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WEIBULL-BASED PARTS FAILURE ANALYSIS COMPUTER PROGRAM USER'S MANUAL

James L. Byers
Air Vehicle and Crew Systems Technology Department (Code 6052)
NAVAL AIR DEVELOPMENT CENTER
Warminster, PA 18974-5000

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This document provides the background and describes the usage of a set of computer codes (WEIBER) which can be used to analyze failure characteristics using a Weibull distribution. Inputs and outputs are described for each of the fourteen programs within the set; this information is presented in the form of sample cases. Explanatory notes are also included.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES

LIST OF FIGURES

NOMENCLATURE

$F(t)$	=	cumulative fraction of a group of parts that has failed by time t.
t	=	variable time
t_o	=	initial time
η	=	ETA or Characteristic Life
β	=	BETA
i	=	rank order
N	=	sample size
N	=	total number of items

INTRODUCTION

The Weibull distribution is a cumulative distribution function which expresses the probability than an item's life is less than some specified value. The distribution arises naturally in mathematical statistics as a limiting distribution of the smallest extremes. The distribution is extremely versatile; it can be used to analyze any class of forecasting problem in which parts fail by wearing out. It is especially useful because it provides accurate failure predictions for an entire population based on limited failure data.

Over the last forty years, individuals in the propulsion community have developed numerous methodologies for determining and assessing parts failures. Because these codes were developed for a variety of different computers and operated separately, it frequently took months to produce failure forecasting data; this limited the utility of the codes. By significantly decreasing the time that it takes to conduct a failure analysis, a Weibull-based methodology can become an effective management tool. Consequently, an integrated set of parts use forecasting codes based on the Weibull distribution have been developed for operation on IBM compatible micro-computers. With these codes, the manager can make rapid first-order estimates of the number of failures to be expected in a given population over some period of time. This capability will allow the user to address a variety of problems such as: evaluating several options to fix fleet problems, establishing minimum operating costs, or trading off development costs against spares costs.

This manual is intended to serve as a user's guide and help document the Weibull-Based Parts Failure Analysis Computer Program. Only that part of the theory of analysis needed to understand the fundamentals has been included since complete coverage is beyond the scope of this manual. Technical details may be found in a companion document, Report No. NADC-89019-60, "Weibull Parameter Calculation and Weibull Monte Carlo Analysis for Analyzing Failures in Gas Turbines and Other Equipment."

Each separate routine is covered with appropriate directions for entering data and comments are included to assist in interpreting the output. Almost all of the computer screens will be shown as they appear on the computer monitor along with the pertinent information, warnings, and guidance.

Each user of the software is encouraged to become as familiar with the theory as possible in order to prevent misuse or misinterpretation of results. There will be changes made to the software as time goes by and all registered owners will be informed as they occur. You are encouraged to contact the Propulsion and Thermal Analysis Branch, Code 6052, at the Naval Air Development Center, at the following number when you have questions:

(215) 441-2568
AV 441-2568

WEIBULL ANALYSIS

SHORT MATHEMATICAL BACKGROUND

The Weibull probability distribution or family of distributions is given by the following expression :

$$F(t) = 1 - e^{\wedge}(-((t-to)/\eta)^{\wedge}\beta) \qquad \textbf{(Weibull function)} \qquad (1)$$

where :

$F(t)$ = cumulative fraction of a group of parts that has failed by time t.

t = variable time

to = initial time. If time is measured since the part was new, then to = 0.

η = ETA or Characteristic Life (time at which 63.2% of the population should fail).

β = BETA slope of the plot or shape parameter. An indication of the failure mode.

It is important to understand that only failure data is plotted on a Weibull graph and that these data points must fall on a fairly straight line. If these points do not fall on a reasonably straight line, then the Weibull probability distribution function does not fit the data and any results or predictions based on the plot may contain a wide margin of error. The Weibull probability distribution function given above is an exponential function of the two parameter types which must be linearity in order to provide for a plot that results in a straight line when the failure data fits the distribution. Once the x and y coordinates are scaled properly, any failure data correlating in a Weibull distribution will plot in a straight line.

Assuming time to failure is measured since the parts are new, or to = 0, then:

$$F(t) = 1 - e^{\wedge}(-(t/\eta)^{\wedge}\beta). \qquad (2)$$

Rearranging :

$$1 - F(t) = e^{\wedge}(-(t/\eta)^{\wedge}\beta)$$

$$\frac{1}{1 - F(t)} = e^{\wedge}(t/\eta)^{\wedge}\beta.$$

Since a linear expression is desired, successive natural logarithms must be taken until all exponentials have disappeared.

$$\ln\left(\frac{1}{1 - F(t)}\right) = (t/\beta)^\beta$$

$$\ln\ln\left(\frac{1}{1 - F(t)}\right) = \beta \ln t - \beta \ln \eta.$$

This last expression is the familiar linear expression given by:

$$\mathbf{Y = Bx + A} \qquad \mathbf{(3)}$$

where:

$$Y = \ln\ln\left(\frac{1}{1 - F(t)}\right)$$

β = slope BETA

$x = \ln t$

$A = -\beta \ln \eta.$

CONSTRUCTION OF WEIBULL PROBABILITY GRAPH

The parameters given in the previous section will provide for the appropriate scales for utilizing Weibull probability paper. For example, the x-axis is a log scale while the y-axis is a double log scale. Note that these parameters denote only the scale of the graph paper. The x-axis still represents life units (hours, cycles, miles, etc.) while the y-axis represents the cumulative probability of failure or cumulative percent of units failing. Care must be taken when choosing the units of life measurement since the wrong units could result in a bad data fit. For example, if the item in question is a part in an aircraft landing gear, then the life measurements should be in terms of numbers of takeoffs plus landings. The following tables show how to scale the X- and Y-axes correctly.

X-AXIS

The scale on the X-axis is given by $x = \ln t$. For a range of hours (1, 10, 100, etc.) the second column gives the relative spacing on the Weibull graph paper between these hours.

t (hours)	ln t
1	0.00
10	2.30
100	4.60
1000	6.91
10000	9.21

Y-AXIS

The scale on the Y-axis is given by the double log expression

$$Y = \ln \ln \left(\frac{1}{1 - F(t)} \right).$$

The third column in the following table gives the relative spacing on this axis.

F(t)	$Y = \ln \ln \left(\frac{1}{1 - F(t)} \right)$	Y + 6.91
0.001 (0.1%)	-6.91	0.00
0.010 (1.0%)	-4.60	2.31
0.100 (10 %)	-2.25	4.66
0.500 (50 %)	-0.37	6.54
0.900 (90 %)	0.83	7.74

Notice that as the probability of failure approaches 0 (zero), F(t) = 0.001, the value of Y approaches -6.91. To avoid the use of negative values, all values of Y are typically increased by 6.91 units. The Weibull probability paper can now be plotted by using the units of the last column of each of the two preceding tables where the units may be inches, centimeters, or any other convenient system. The usual is to use inches for reasonable sized plots. A sample of Weibull plotting paper is shown on the next page.

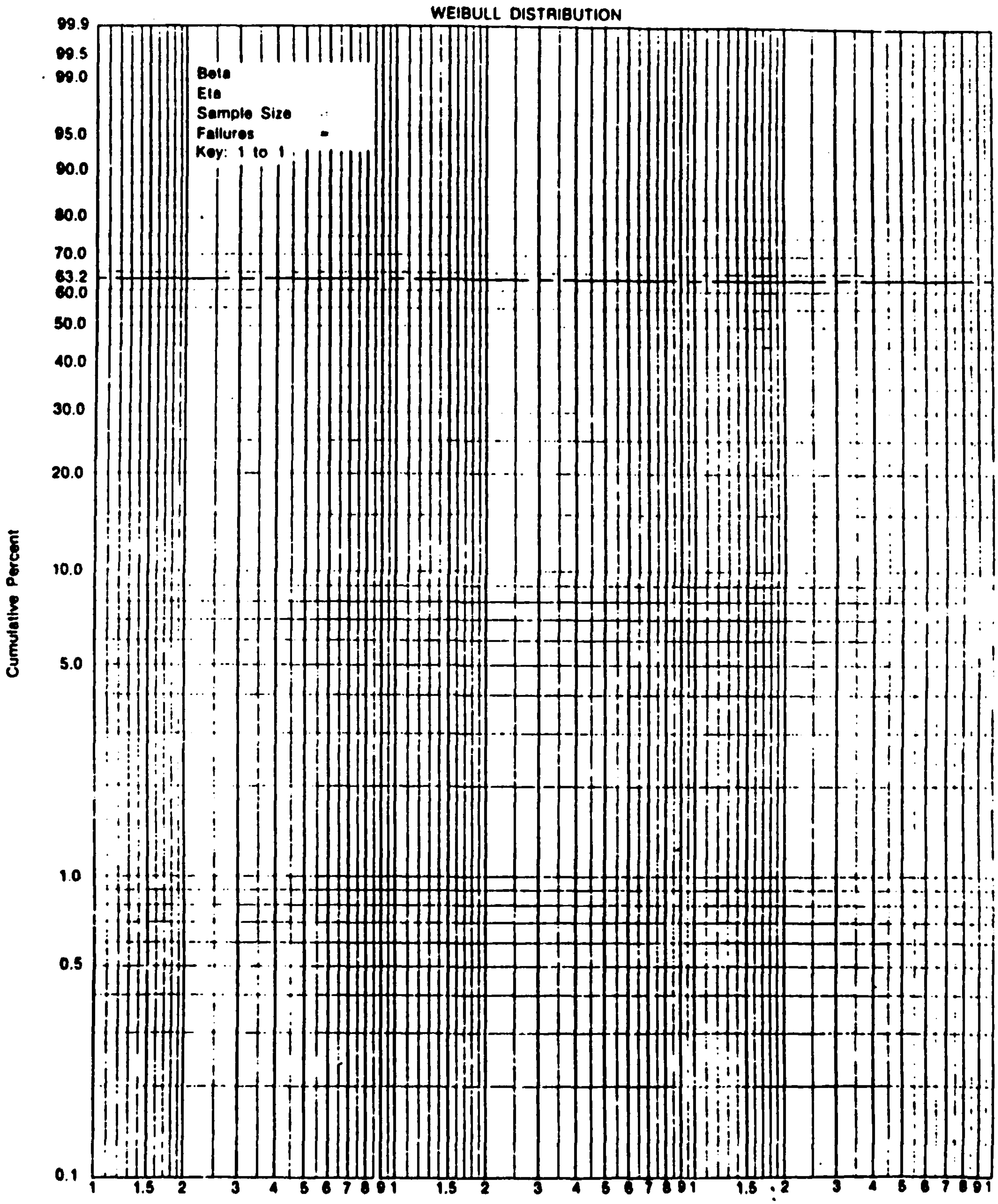

Figure 1. WEIBULL Probability Paper

PLOTTING POINTS ON WEIBULL PAPER

The first step in establishing a Weibull plot is to arrange a given sample of data in ascending order of life units (from low to high values). A typical sample of data consists of items that have failed and items that have not failed, or have failed under a different failure mode than that of interest. Non-failed and other modes of failures are called suspensions. It is important to recognize that only one failure mode should be plotted on any Weibull plot. A mix of failure modes will result in either a slope very close to one (1), indicative of random failures, or a completely erroneous and non-correlating plot. Combining failure modes is never a correct procedure and usually results in data scatter. Consider the following sample of data :

Item #	Hours	Failure ?
1	2892	yes
2	4367	yes
3	5398	yes

This sample of data consists of three units, all of which have failed. In order to plot these points, one needs to know the x-coordinates and the y-coordinates. The x-coordinates are simple since they are merely the time in hours of each failure. The y-coordinates are not quite as simple though. Each failure in a group of units will have a certain percentage of the total population failing before it. These values are seldom known but are needed since they represent the y-coordinate F(t) of the failure data. It is an accepted convention in the literature to use median ranks for establishing the ranks, or plotting positions F(t). Some authors and investigators make minor variations but the results are almost always extremely close to the following expression for median rank :

$$P(mr) = \frac{i - 0.3}{N + 0.4} \times 100 \qquad (4)$$

where

P(mr) = median rank (plotting point)

i = rank order

N = sample size.

Calculating the median ranks for the preceding sample data results in the following :

item #	rank order	median rank
1	1	20.6
2	2	50.0
3	3	79.3

example calculations

item 1 $$P(mr) = \frac{1 - 0.3}{3 + 0.4} \times 100 = 20.6$$

item 2 $$P(mr) = \frac{2 - 0.3}{3 + 0.4} \times 100 = 50.0$$

item 3 $$P(mr) = \frac{3 - 0.3}{3 + 0.4} \times 100 = 79.3$$

To plot this data simply start with item 1 data of P(mr) = 20.6 and t = 2892 hours. Where these coordinates meet on the Weibull paper place the point for item one. The other two data pairs are similarly plotted. As long as all the items in the sample are failures the item numbers and rank order values will always be the same.

Suppose the new information indicated that item 2 failed by a different failure mode than items 1 and 3.

Item #	Hours	Failure ?
1	2892	yes
2	4367	no <-------
3	5398	yes

In this case only items 1 and 3 are plotted. However, suspended items (such as item # 2 above) cannot be ignored when establishing the Weibull plotting points. When suspended items are present never use the previously outlined method to determine the plotting points.

The rationale for including the suspended items in the analysis is that if the suspended failure had occurred in the same mode as the other failures, the rank order of the other failures would have been influenced. Therefore, some adjustment of the rank orders must be exercised in order to account for the potential influence of the failure of this item. This is done by adding a rank increment to the units failing after the suspended item. The rank increment is given by:

$$\text{Rank Increment} = \frac{(N + 1) - (\text{previous rank})}{1 + (\text{\# of items beyond present suspended item})} \quad (5)$$

where:

N = total number of items

Since item 3 failed after a suspension, its rank order must be adjusted according to the above relation. When using this relation it is important to realize that the previous rank order to item 3 is the rank order corresponding to item 1. The reason for this seeming oddity is that suspended items do not have either a rank order or a median rank since they are not to be plotted on the Weibull graph.

In the current example:

$$\text{Rank Increment} = \frac{(3 + 1) - 1}{1 + 1} = 3/2 = 1.5$$

The adjusted order for item 3 is the rank order of the previous failure (item 1) plus the calculated rank increment.

1 + 1.5 = 2.5 <----- (new rank order for item 3)

The plotting points are found as before resulting in the following:

Item #	Failure ?	Rank Order	Median Rank
1	yes	1	20.6
2	no	-	-
3	yes	2.5	64.7

The median ranks were calculated the same as in the previous example.

Using the above method, data samples (regardless of whether they contain suspensions or not) can be plotted on Weibull paper. Once the data are correctly plotted, a straight line is fitted through the points. The slope, Beta, is calculated by measuring the rise along the y-coordinate and the run along the x-coordinate. The slope, Beta, is then the rise (in inches) divided by the run (in inches). To obtain the characteristic life η (ETA), find the 63.2% point on the Y-axis, observe where a horizontal line drawn though this point intersects the line drawn through the plotting points, and read the corresponding life measurement on the X-axis. The characteristic life always occurs at 63.2% probability of failure. By examining the Weibull function (Equation (2)) the reason becomes evident.

$$F(t) = 1 - e^{(-(t/\eta)^{\beta})}$$

When failure time t coincides with characteristic life η, or $t = \eta$, then the Weibull function reduces to :

$$F(t) = 1 - e^{(-(1)^{\beta})} \quad (6)$$

$$= 1 - 0.368$$

$$= 0.632 \quad \text{or} \quad 63.2\%$$

When $t = \eta$, F(t) is always 63.2% regardless of the slope β.

RISK ANALYSIS

One of the most useful properties of Weibull analysis is the ability to forecast or estimate the expected number of failures that will occur over some period of time (present or future). This is important since it will give the engineer or analyst a measure of the gravity of the problem and might even suggest what type of corrective action may be appropriate. After plans are developed for corrective action, risk analysis can be repeated to verify the effects of the action taken (inspection intervals, redesign, etc.). The next two sections cover present and future risk analysis. In these analyses, it is assumed that parts that fail are not repaired and put back in service. The systems they are taken from are therefore dropped from the analysis after failure. If parts are replaced and systems go back in service, they become a part of another sample with those parts replaced being counted as placed in service with zero time. The failed parts therefore only contribute to the total failure risk in the original sample while they are in operation, up to time of failure. In order to perform these analyses, the failure data must be plotted as shown in the previous sections. The parameters η (Eta) and β (Beta) are required, along with the number of units and the life measurement of the units (both failures and suspensions). For future risk analysis the expected utilization rate over a future time period will also be required.

PRESENT RISK ANALYSIS

For a given sample population, present risk analysis determines the expected number of failures from zero time (when the part was new) to the present date. One of the applications of present risk analysis is to verify the accuracy of the parameters Beta and Eta and the data fit to the Weibull plot. If the expected number of failures given by the present risk analysis is very close to the observed failures, then the quality of the data fit can be assumed good. If not, there may be several reasons why. The sample used in the present risk analysis may not be representative of the same quality of manufacture as the original sample (from a different population entirely), or the present risk analysis sample may contain items with batch problems in the same failure mode. Generally speaking, the present risk analysis will give

fairly good correlation in the average case without significant differences.

Present risk is obtained in the following manner: for a population of N items or units where each has accumulated the same t hours, the expected number of failures within this population is the probability of failure of these units by time t multiplied by the number of units N.

$$\mathbf{PresRisk = F(t) \times N} \tag{7}$$

where:

$$F(t) = 1 - e^{(-(t/\eta)^{\beta})}. \qquad (\text{ if to } = 0 \text{ })$$

Therefore, for a sample of data (failures and suspensions), group the units into those having equal operating time (life). For each of these groups with equal life, read F(t) from the Weibull plot (or calculate the value with the above formula) and multiply it by the number of units in that group. Repeat for all groups (groups may contain one or many units) in the sample data and add the results to obtain the total expected failures from the population.

# of Units	Hours	F(t)	F(t) x N
5	1000	0.001	0.005
2	2000	0.500	1.000
1	5000	0.750	0.750
		total expected failures =	1.755

It is very important to realize that these calculations must be done for all units or groups of units in the sample data (failures and suspensions) since even the failures contribute to the total risk while they are in operation. This analysis gives the total number of units expected to fail from the sample data. If the sample data represents only a fraction of the total units in operation, then extreme care must be taken in extrapolating the total number of failures. In order for accuracy to be preserved, the age distribution of the sample data must closely resemble the age distribution of the total population.

FUTURE RISK ANALYSIS

One of the most important uses of the Weibull analysis technique is the ability to forecast how many units of a data sample are expected to fail during a specified time period. When the measure of life is hours, it is necessary to estimate the number of additional hours the each unit will accumulate during this future time period (6, 12, 18, 36, 48 months, etc.). If you use cycles or some other life measurement, then estimate the number of cycles, etc., that will be accumulated. If a unit has -accumulated t hours without failure and is expected to accumulate u additional hours in the future, then that unit's contribution to the total future risk is given by:

$$\textbf{FutRisk} = \frac{F(t + u) - F(t)}{1 - F(t)} \tag{8}$$

Again, F(t + u) and F(t) can be either read from the Weibull plot or calculated. In many cases, F(t) will be much less than 1.0 and the future risk expression above can be very accurately simplified to :

$$\textbf{FutRisk} = F(t + u) - F(t) \tag{9}$$

As in present risk analysis, the future risk calculation must be repeated for every unit or group of units in the data sample (failures and suspensions) and the contribution of each unit to the total risk must be added together to obtain the expected total future failures for the data sample.

# of Units	Hours	F(t+u)	F(t)	$\frac{[F(t+u)-F(t)]}{1 + F(t)} \times N$
5	1000	0.003	0.001	0.010
2	2000	0.700	0.500	0.800
1	5000	0.900	0.750	0.600
total failures during u hours future period =				1.410

For this analysis it is assumed that failures are not repaired and put back in service. If they are repaired, they then immediately become a part of another, completely different, data sample. In later sections of this manual, one of the software routines (WEIBRISK) provides a method for calculating future risk when units are inspected and/or repaired at specific intervals. Provisions are also made to return the repaired units to service and continue calculating subsequent failures.

ADVANTAGES OF WEIBULL ANALYSIS

One of the clear advantages of Weibull analysis is that a reasonable portion of the useful information it provides can be obtained by simple inspection of the graphical results. Together with the software package, which greatly facilitates the mathematical manipulations and graphical presentation, a Weibull analysis can be an excellent tool to aid in engineering decision making.

Another advantage of Weibull analysis is that it may be applied with good results even with the inadequacies in data obtained using poor data collection systems, incomplete field data and other problems such as extremely small failure samples (even zero failures). The technique even provides good results if the time on unfailed units is not known. This ability of Weibull techniques to provide good results when there is only very meager data is especially useful for those cases where safety is a paramount issue and failures cannot be tolerated.

When combined with good engineering judgment and good management techniques, Weibull analysis results can assist in determining or evaluating the many choices available when making engineering changes or redesigns, regular maintenance plans, warranties, optimum inspection intervals, dominant failure modes, and impacts of the many what-if questions that always arise. When combined with life cycle cost analysis there can be evaluations which may significantly impact the bottom line profit picture.

LIMITATIONS OF THE WEIBULL ANALYTICAL TECHNIQUES

Weibull techniques are ideally suited for analyzing one part or component that fails in a single predominant failure mode. If the part regularly experiences more than one failure mode and all failures are lumped together the accuracy of the analysis will be severely impacted. Graphically there will be a bad fit of the data and a straight line plot will not be possible. This generally happens when an entire system is analyzed and no differentiation is made between failures in different parts which occur in a different manner or failure mode.

When working with small numbers of failures (two or three) the slope Beta tends to be higher than it should be and the characteristic life Eta tends to be lower than it should. As the amount of data increases the Weibull parameters tend to stabilize. Therefore, the initial estimates of Beta and Eta can be considered very conservative, depending on the amount of data available. For critical parts (where safety is a concern) this can be an advantage. More accurate results are usually obtained by using maximum likelihood estimates (MLE). Maximum likelihood estimates are the values of Beta and Eta which maximize the likelihood of obtaining the observed data. As a rule, MLE should be used when doing risk analyses. For small failure data the MLE method will also provide a conservative estimate, but somewhat closer to the true values based on observed data than those of the Rank Regression method. The only disadvantage of the MLE method is that it is very computationally labor intensive. The software package will provide a way around this problem and complete both Rank Regression and Maximum Likelihood values in a very short time.

When using Weibull analysis, like any other engineering tool, it is extremely important to understand its limitations and capabilities. Above all, good engineering judgment should prevail. The user should closely study the data to determine what to expect from a Weibull analysis. If the units failing were all manufactured together or if there are lower and higher time units that are not failing, there is a strong possibility of a "batch" problem and any conclusions obtained through a Weibull analysis will apply only to that batch. Similarly, if all the failures came from one operational location, it may be that there is a local maintenance deficiency at that location which does not reflect the characteristics of the rest of the population operating elsewhere.

INTRODUCTION TO THE WEIBULL ANALYSIS SOFTWARE

The following sections of Part one consist of step-by-step, detailed instructions for using the Weibull software which is titled "WEIBER" and currently in Version 7, dated 11 July 1988. From time to time new versions are issued to account for new information, special requirements, or to reflect changes for ease of use. Registered users are notified of updates as they occur. There are currently fifteen routines (codes) in Version 7. Each of the fifteen routines is listed in the menu shown in figure (2). Each of these codes will be covered to various degrees, starting with an introduction to explain the function of the routine, required input data, consistency of the output, and other instructions and comments. The introduction will be followed by the actual screens as they appear on the computer monitor. Most screens have footnotes containing pertinent information, instructions and warnings. These footnotes are not part of the screen, but are added to clarify the data input process and to briefly explain the significance of the output.

Some portions of the output require detailed explanations. In such cases the appropriate page number in earlier sections of this manual will be referenced. Although many of the routines require the same input, the program does not necessarily allow an input file created in one routine to be used in another. In some codes a special format is required that is not suitable for another code with the same type input data. Generally, the following compatibility is available between codes:

A. Input files created under routine 1 can be used in routine 15.

B. Input files created under routine 6 can be used in routine 7.

C. In order to use routines 11 and 12, an input file must be created using routine 10.

To access any of the routines in the software package the appropriate routine number from the menu must be entered. To "call up" this menu, boot your computer and make drive A the default drive. Then:

1. Place the Weibull diskette in drive A.
2. Turn on Caps Lock.
3. Type in WEIBER at the A> prompt.
4. Press Enter or return.
5. The menu should now appear on the screen.

If you have a problem with compatibility, try copying your computer Command.com file to the diskette. It may also be necessary to copy your Graphics.com to the diskette. The degree of compatibility with the IBM standards will govern the changes that may have to be made.

```
                            MENU
                   WEIBULL ANALYSIS ROUTINE

 1. WEIBULL PARAMETER CALCULATION AND SAVE INPUT DATA (PWA CO)
 2. WEIBULL PARAMETER CALCULATION W/MAX. LIKELIHOOD VALUES (PWA)
 3. CHARACTERISTIC LIFE CALCULATION.
 4. WEIBAYES - WHEN WEIBULL PLOTS ARE IMPOSSIBLE.
 5. HISTORICAL VALUES OF BETA.
 6. PRESENT RISK ANALYSIS.  (SAVE DATA)
 7. FUTURE RISK ANALYSIS.  (SAVE DATA)
 8. CONFIDENCE INTERVAL CALC FOR BETA & TIME TO FIRST FAILURE
 9. RELIABILITY AND CONFIDENCE INTERVAL FOR RELIABILITY.
10. WEIBULL FAILURE ANALYSIS - MONTE CARLO ANALYSIS.  (SAVE DATA)
11. WEIBULL FAILURE ANALYSIS - SHORT PRINT-OUT.  (RETRIEVE DATA)
12. WEIBULL FAILURE ANALYSIS - FOR OVER 1100 SYSTEMS/PARTS.
    (RETRIEVE DATA)
13. ZERO FAILURE TEST PLAN FOR SUBSTANTIATION TESTING.
14. NON-ZERO FAILURE TEST PLAN GENERATION.
15. GRAPHICS DISPLAY FOR YOUR WEIBULL PLOT.
16. FOR FUTURE USE - NOT YET AVAILABLE
17. FOR FUTURE USE - NOT YET AVAILABLE
18. FOR FUTURE USE - NOT YET AVAILABLE

TO CONTINUE CHOOSE OPTION NO. OR 900 TO QUIT. ?
```

FIGURE 2:   MENU SCREEN

PROGRAM 1. WEIBULL PARAMETER CALCULATION AND SAVE DATA

This routine calculates the Weibull parameters β (slope Beta) and η (characteristic life Eta). These values are used by most of the other routines on the Weibull menu. Suspensions are items or units that have not failed or have failed by a different failure mode than that of current interest.

Input data:

1. Name and date (optional)
2. Part designation (optional)
3. Failure problem name (optional)
4. Units of life measurement (optional)
5. Histogram consisting of numbers of units and time on units (required)

Output data:

1. Slope β
2. Characteristic life η
3. Least squares correlation coefficient
4. Instantaneous failure rate vs age
5. Maximum likelihood values of β and η

The following pages are the computer screens in the order that they appear when using this routine.

```
THIS CODE CALCULATES WEIBULL PARAMETERS
AND SAVES A DATA FILE OF INPUT
FOR LATER UPDATING AND/OR RECALCULATION


PRESS ANY KEY TO CONTINUE
```

FIGURE 3: WEIBULL PARAMETER CALCULATION SCREEN 1

```
1) CREATE A FILE

2) RETRIEVE A FILE

3) VERIFY A FILE

4) EDIT A FILE

5) CALCULATE BETA AND ETA

6) STORE YOUR DATA

7) QUIT
```

FIGURE 4: WEIBULL PARAMETER CALCULATION SCREEN 2

NOTES:

1) Choosing option 1 will result in screen 3.

2) When retrieving a file, the name of the desired file will be requested. The file will not be shown on the screen. To see the file choose option 3.

3) Option 4 allows a file to be edited. A help file is available. Other options are self explanatory.

```
ENTER YOUR NAME & THE DATE: J. L. BYERS

ENTER THE PART DESIGNATION: WIDGET

ENTER FAILURE PROBLEM NAME - PART, COMPONENT, MODE, etc.: WEAR

ENTER UNITS OF LIFE MEASUREMENT - HOURS, CYCLES, etc.: HOURS

ARE YOU INPUTTING A HISTOGRAM OF SUSPENSIONS ? (Y/N): Y

AN INTERVAL SIZE OF 50 IS ASSUMED, O.K. ? (Y/N): N

ENTER THE INTERVAL SIZE YOU WILL USE: 500



     ENTER THE NUMBER OF SUSPENSIONS IN EACH INTERVAL
          USE -99999 TO INDICATE THE END

     0    - 500          0
     500  - 1000         0
     1000 - 1500         0
     1500 - 2000         2
     2000 - 2500         1
     2500 - 3000         3
     3000 - 3500         12
     3500 - 4000         18
     4000 - 4500         19
     4500 - 5000         44
     5000 - 5500         41
     5500 - 6000         51
     6000 - 6500         33
     6500 - 7000         13
     7000 - 7500         3
     7500 - 8000         7
     8000 - 8500         4
     8500 - 9000         1
     9000 - 9500         -99999
```

FIGURE 5: WEIBULL PARAMETER CALCULATION SCREEN 3

NOTES:

1) Choose a measurement of life that is appropriate to the function of the part to be analyzed. Data should be routinely gathered using the appropriate life units.

2) If the number of suspensions is large, it is best to input a histogram of suspensions. The use of a histogram allows grouping of many suspensions in time intervals rather than entering each separately

   Note you can choose your desired interval or use the default value. Intervals should be as small as practical to preserve accuracy. If the sample size is small (15 or less) input all failures and suspensions individually.

```
        ENTER THE FAILURE AND SUSPENSION TIMES

    IF HISTOGRAM OF SUSPENSIONS HAS BEEN ENTERED,
    ENTER ONLY FAILURES AT THIS TIME


    POSITIVES ARE TREATED AS FAILURES
    NEGATIVES ARE TREATED AS SUSPENSIONS
    USE -99999 TO INDICATE END OF DATA


> 2892
> 4367
> 5398
>-99999
```

FIGURE 6: WEIBULL PARAMETER CALCULATION SCREEN 4

NOTES:

As discussed for screen 3, for small samples where the exact time is known for all failure and suspensions, enter the data in ascending order of time on the units. Observe the sign convention of positive for failure and negative for suspensions. If a histogram of suspensions was entered in screen 3 then only failure times are needed here. If two units failed with equal time of service, enter this time twice. There must be a one-to-one correspondence between the number of units and the times entered. When all data is entered, screen 2 will return. You may now choose to store your data for later recalculation or updating prior to calculating Beta and Eta. If the data is not stored the calculations will destroy the data which will prevent its later use.

POINT (A)	DATA (B)	ORDER(C)	MEDIAN RANK (D)
1	2892	1.023904	2.82334E-03
2	4367	2.297417	7.790239E-03
3	5398	4.512222	1.642832E-02
4	7724	22.54706	8.676703E-02

BETA = 3.61568 ETA = =15755.66 (E)

R = .985064 R SQUARED = .970351 (F)

INSTANTANEOUS FAILURE RATES VS AGE (G)

AGE	INST F/R
20	6.090895E-12
40	3.733182E-11
60	1.078146E-10
80	2.288112E-10
100	4.10169E-10
200	2.513974E-09
400	1.540845E-08
600	4.449973E-08
800	9.444022E-08
1000	1.692944E-07
2000	1.037625E-06
4000	6.35973E-06
6000	1.836695E-05
8000	3.897954E-05
10000	6.987506E-05

MAXIMUM LIKELIHOOD ESTIMATES FOLLOW (H)
BETA = 4.050808 ETA = 15787.52

ENTER THE FAILURE AND SUSPENSIONS TIMES

IF HISTOGRAM OF SUSPENSIONS HAS BEEN ENTERED,
ENTER ONLY FAILURES AT THIS TIME

POSITIVES ARE TREATED AS FAILURES
NEGATIVES ARE TREATED AS SUSPENSIONS
USE -99999 TO INDICATE END OF DATA

> 2892
> 4367
> 5398
> -99999

FIGURE 7: WEIBULL PARAMETER CALCULATION SCREEN 5

NOTES:

1.

A) Data points to be gathered - equal to number of failures.

B) Time on part/component (hours, cycles, etc.). The x-coordinate of the weibull plot.

C) Rank order. For explanation of this parameter. See page 6.

D) Median rank. See also page 7.

E) Slope Beta and characteristic life Eta.

F) R Squared is the least squares correlation coefficient. It is a measurement of the amount of scatter in the data. An ideal value would be 1 (one) which would indicate a perfect correlation (all points would fall on a straight line on the Weibull plot). A value very close to one indicates good correlation most of the time. Always plot the data to be sure.

G) The instantaneous failure rate is also known as the hazard rate and is presented in terms of failures per hour. These values cannot be obtained directly from the Weibull plot.

H) Maximum likelihood estimates are the values of Beta and Eta that maximize the likelihood of obtaining the observed data. Page 10 addresses some of the advantages of using these values when doing risk analyses.

2. This routine should be used in conjunction with routine 15 (the graphic Weibull plotting routine). Recall that the file created in this routine can be used in the graphics routine as well.

PROGRAM 2. WEIBULL PARAMETER CALCULATION W/MAX LIKELIHOOD VALUES

This routine uses the same method to calculate Weibull parameters but does not store data files nor does it automatically print a hard copy. The required input data is similar to that of the first routine. No screens are shown for this routine.

PROGRAM 3. CHARACTERISTIC LIFE CALCULATION

This routine calculates the characteristic life ETA (η) when an approximation of BETA (β) is available. A range of BETA values are frequently known because the failure mode usually defines the range for a given type of equipment. (Refer to code number five on the menu for a historical reference of BETA values). This code is especially useful when no failure data is available or the time on failed units is not known. Without failure data, it is impossible to calculate the exact values of BETA and ETA using code number one of the menu. With an approximation of BETA at hand from code number five, or other source, this code calculates an approximation of ETA such that other calculations can be made that require the values of BETA and ETA to be known. This code assumes that a failure is impending if there have not been previous failures that are known. While this may not be true in all cases, the answer that you get will be conservative in that it will yield a lower value of ETA than the true value.

Input data:

1)	Name and date	(optional)
2)	Part designation	(optional)
3)	Failure problem name	(optional)
4)	Units of life measurement	(optional)
5)	Value of BETA to be used	(required)
6)	Total number of known failures (enter 1 if there have been no failures)	(required)
7)	Histogram of suspensions	(required)

Output:

1) Histogram entered
2) Calculated value of ETA
3) Value of BETA used (same as 5 above)

```
                    PROGRAM ETACALC


     CALCULATION OF THE CHARACTERISTIC LIFE ETA
   BASED ON KNOWN FAILURES AND WEIBULL SLOPE BETA




            PRESS ANY KEY TO CONTINUE
```

FIGURE 8: ETACALC SCREEN 1

```
1) CREATE A FILE

2) RETRIEVE A FILE

3) VERIFY A FILE

4) EDIT A FILE

5) CALCULATE ETA

6) STORE YOUR DATA

7) QUIT
```

FIGURE 9: ETACALC SCREEN 2

NOTES:

If creating a file, choose this option and proceed to screen 3.

```
ENTER YOUR NAME & THE DATE: J. L. BYERS

ENTER THE PART DESIGNATION: WIDGET

ENTER FAILURE PROBLEM NAME - PART, COMPONENT, MODE, etc.:
WEAR

ENTER UNITS OF LIFE MEASUREMENT - HOURS, CYCLES, etc.:
HOURS

ENTER THE VALUE OF BETA TO USE: 4.051

ENTER THE TOTAL NUMBER OF FAILURES -
IF THERE ARE NO FAILURES, INPUT 1 : 4
```

FIGURE 10: PROGRAM ETACALC SCREEN 3

NOTES:

1) If the failure mode is known, an approximation of Beta can be obtained using historical values (routine 5).

2) If the number of failures is known, enter the number here. If there have been no failures, enter "1" - do not enter 0. This assumes that there is a failure impending and will give a conservative estimate of Eta (less than the actual value). Entering 0 (zero) will cause a 'divide by zero' error and halt the program.

```
        ENTER THE NUMBER OF UNITS AT TIME T1 - AND THEN -

        ENTER THE TIME T1


        USE -99999 TO INDICATE END OF DATA

> 2
> 1775
> 1
> 2225
> 3
> 2775
> 12
> 3225
> 18
> 3775
> 19
> 4225
> 44
> 4775
> 41
> 5225
> 51
```

FIGURE 11: PROGRAM ETACALC SCREEN 4

NOTES: In routine 1, since there were a large number of suspensions, the data was grouped in 500 intervals. In this routine the input is different and there are no provisions to input a histogram of suspensions. Each group of units must be assigned a specific time or they must be entered individually. For a very large number of units it would be too time consuming to enter the time for each individual unit. Furthermore, the individual ages may be unknown and only an approximation can be made in some cases. One solution is to use the mid-range of the 500 hour interval as we had in routine 1. Note that in routine 1 no units existed with less than 1500 hours and zeros were entered for these time intervals. This routine does not recognize zero units for any given time. Therefore start with the first real time (1775) and skip any interval with zero units.

CALCULATION OF THE CHARACTERISTIC LIFE ETA
BASED ON KNOWN FAILURES AND WEIBULL SLOPE BETA

DATA PAIRS : (NO. OF PARTS AND TIME ON PARTS)

2, 1775, 1, 2225, 3, 2775, 12, 3225, 18, 3775, 19, 4225, 44, 4775, 41, 5225, 51, 5775, 33, 6225, 13, 6775, 3, 7225, 7, 7775, 4, 8225, 1, 8775,

THE CALCULATED VALUE OF ETA IS 15720.21

THE VALUE OF BETA USED IS 4.051

FIGURE 12: PROGRAM ETACALC SCREEN 5

NOTES:

1) Data pairs as they were entered.

2) The calculated value of Eta is presented. It was calculated using unknown failure times (only the number of failures was known. Compare with the maximum likelihood value of routine 1.

PROGRAM 4. WEIBAYES - WHEN WEIBULL PLOTS ARE IMPOSSIBLE

When no failure data is available, this code will calculate the critical life of an item when given the percentage of the total population that will be allowed to fail and the estimated values of BETA and ETA. The estimated values of BETA and ETA can be obtained from historical values if the failure mode is known. Once BETA is estimated, use the previous code to estimate ETA.

This code requires the percentage of the total population which will be allowed to fail. If the item is a critical part which cannot be allowed to fail because of the fatal consequences, then choose a value such as 0.01 % (input in decimal form as 0.0001). The code returns a critical life, or operating time, that may be accrued prior to the stated percentage of failures occurring. If failure data was available a Weibull plot would be possible and the critical life could be read directly from the plot.

Input data:

1)	ETA	(required)
2)	BETA	(required)
3)	Percentage of the population that will be allowed to fail	(required)

Output:

1) Critical life

```
                WEIBAYES ANALYSIS
          WHEN WEIBULL PLOTS ARE IMPOSSIBLE
            DUE TO A LACK OF FAILURE DATA


DO YOU KNOW THE VALUE OF THE CHARACTERISTIC LIFE
(INPUT <Y> OR <N>? Y
```

FIGURE 13: WEIBAYES ANALYSIS SCREEN 1

NOTES: If the value of ETA is known, enter "Y" and proceed to screen 2. An input of "N" will result in routine 3 (characteristic life calculation) being run.

```
ENTER THE BETA-LIFE OR PERCENTAGE OF THE POPULATION ALLOWED
TO FAIL. THIS IS THE PERCENTAGE OF THE POPULATION FOR
WHICH THE OPERATING TIME WILL BE CALCULATED TO HAVE OCCURRED
PRIOR TO THIS PERCENT OF FAILURES.

ENTER AS A DECIMAL, i.e., .001 FOR B.1 LIFE.
DO NOT USE 1.0 OR ANY PERCENT > .999999.

               B LIFE = .001

ENTER THE ASSUMED VALUE OF BETA FOR THE FAILURE MODE:
4.051

ENTER THE VALUE OF THE CHARACTERISTIC LIFE FOR THE
FAILURE MODE: 15788
```

FIGURE 14: WEIBAYES ANALYSIS SCREEN 2

NOTES: Inputting B LIFE = .001 represents 0.1% of the population. After all values have been entered, screen 3 will follow with the output. Other input is self explanatory.

```
                    LIFE CALCULATION FOR WEIBAYES

PERCENT OF POPULATION ALLOWED TO FAIL = .1000047 (CALCULATED
VALUE).

THE CALCULATED LIFE USING THE INPUT VALUE OF BX IS EQUAL TO
2869.601

IF THIS VALUE IS SMALLER THAN ACCEPTABLE THEN THE CALCULATED
VALUE OF ETA (CHARACTERISTIC LIFE) IS TOO SMALL. THIS MAY BE DUE TO
A LACK OF SUFFICIENT OPERATING TIME USED IN THE CALCULATION OF ETA.
INSUFFICIENT DATA A NEED TO EXPERIENCE CONSERVATISM UNTIL ENOUGH
OPERATIONAL EXPERIENCE IS OBTAINED WITHOUT A FAILURE (OR FEW
FAILURES) SUCH THAT A HIGHER VALUE OF ETA IS CALCULATED.

BETA USED WAS 4.051      ETA USED WAS 15788.
```

FIGURE 15: WEIBAYES ANALYSIS SCREEN 3

PROGRAM 5. HISTORICAL VALUES OF BETA

Running this code will result in a print-out of historical values of BETA for various failure modes in aircraft gas turbines. Also included are various interpretations of certain numerical values of BETA. Some values are presented as ranges. While the values are generally felt to be good places to start if there is no other information available, they should not be taken as absolute under any circumstances. They should be used to establish trends and interpreted as the trends that would result only if the values happen to be correct. Use these values cautiously, especially for equipment other than aircraft gas turbines.

```
***** VALUES OF BETA (WEIBULL SLOPE) FROM HISTORICAL TRENDS ****
        EXTRAPOLATE VERY CAUTIOUSLY FOR OTHER EQUIPMENT


* BEARINGS, GENERAL FAILURES.....................1.5
* CRACK, FLANGE..................................9.5
* EROSION, TURBINE VANE..........................3.0
* LCF COMPRESSOR CASE............................5.0
* LCF COMPRESSOR DISK............................3.0
* NOZZLE BEARINGS................................1.5
* LCF GENERAL....................................2.0--->5.0
* PERFORMANCE DETERIORATION......................4.0--->5.0
* ROTATING STRUCTURE.............................6.0--->8.0
* STATIC STRUCTURE...............................4.0--->6.0
* THERMAL LCF, COMBUSTOR.........................3.0


    * INDEPENDENT OF TIME
    * INGESTION (FOD) AND MISUSE
    * INSUFFICIENT REDUNDANCY
    * MAINTENANCE ERRORS
    * MIXTURE OF PROBLEMS
    * ORIGINAL DESIGN DEFICIENCIES
    * RANDOM FAILURES................................1.0


* SLOPES LESS THAN 1.0 ARE INFANT MORTALITY WHERE RELIABILITY WILL
INCREASE  WITH AGE.  ALSO INDICATES A QUALITY PROBLEM SUCH AS
MISASSEMBLY USUALLY HAS A VALUE AROUND 0.5.

* SLOPES GREATER THAN 1.0 ARE GENERALLY WEAROUT FOR ONE REASON OR
ANOTHER.

* A SLOPE OF 2.5 IS USUALLY GRADUAL WEAROUT.

* A SLOPE OF 3.44 APPROXIMATES A BELL SHAPED CURVE (NORMAL
DISTRIBUTION).

* A SLOPE GREATER THAN ABOUT 4.5 ARE USUALLY RAPID WEAROUT (BRICK
WALL).
```

FIGURE 16: BETAHIST OUTPUT SCREEN 1

PROGRAM 6. PRESENT RISK ANALYSIS

This code calculates the expected number of failures to date for a given sample population. As explained earlier, this code is very useful in verifying the accuracy of the data fit. If the calculated number of expected failures is close to the observed number of failures, the accuracy of the data fit is confirmed as good. Of course the population size should be the same in each case, i.e., when calculating BETA and ETA and when calculating the present risk.

Input data:

1)	Name and date	(optional)
2)	Part designation	(optional)
3)	Failure problem name	(optional)
4)	Units of life measurement	(optional)
5)	Histogram of failures and suspensions	(required)
6)	Values of BETA and ETA	(required)

Output:

1) Histogram entered
2) Percent failures and number of failures for each group of units in the histogram
3) Total number of failures for the population
4) Values of BETA and ETA used

PRESENT RISK ANALYSIS
VERSION OF 3 NOV 87

YOU WILL NOW ENTER DATA DIRECTLY OR CREATE A FILE FOR LATER UPDATING AND/OR RECALCULATION

YOU MAY ALSO RECALL AND UPDATE AN EXISTING FILE

PRESS ANY KEY TO CONTINUE

FIGURE 17: PRESENT RISK ANALYSIS SCREEN 1

SELECT FROM THE FOLLOWING :

1) CREATE A HISTOGRAM FILE

2) RETRIEVE A HISTOGRAM FILE

3) VERIFY A HISTOGRAM

4) EDIT A HISTOGRAM FILE

5) STORE YOUR HISTOGRAM FILE

6) RETURN TO PRESRISK

7) QUIT

FIGURE 18: PRESENT RISK ANALYSIS SCREEN 2

```
ENTER YOUR NAME & THE DATE: J. L. BYERS

ENTER THE PART DESIGNATION: WIDGET

ENTER FAILURE PROBLEM NAME - PART, COMPONENT, MODE, etc,: WEAR

ENTER UNITS OF LIFE MEASUREMENT - HOURS, CYCLES, etc.: HOURS

ENTER YOUR HISTOGRAM (UNITS & TIME ON UNITS) HERE

ENTER NUMBER OF UNITS WITH APPROXIMATELY THE SAME LIFE
THEN ENTER TIME ON THESE UNITS (OR CYCLES, etc.)

USE -99999 TO INDICATE END OF DATA

>
> 2
> 1775
> 1
> 2225
> 3
> 2775
> 12
> 3225
> 18
> 3775
> 19
> 4225
> 44
> 4775
> 41
> 5225
> 51
> 5775
> 33
> 6225
> 13
> 6775
>
```

FIGURE 19: PRESENT RISK ANALYSIS SCREEN 3

NOTES: This histogram consists of failure and suspensions combined. It is not necessary to distinguish between failures and suspensions for this routine since both contribute to the total risk. Since the failures were once part of the original population, they also contribute to the total risk. Note that the data input process is not as flexible as in routine 1. In this routine, large numbers of units are not grouped into time intervals.

Therefore, a particular time must be chosen to group the units into or they must be entered singly. For purposes of demonstration, the mid-range of the 500 hour intervals used in routine one is chosen.

warning

Note that in routine 1 there were no units with less than 1500 hours, and 0 (zero) units were entered for these time intervals.

In Present Risk, (routine 6), do not enter 0 (zero) units for a time where there are no units present. This routine will not recognize a 0 (zero) for the number of units and will mix up the data. To avoid this problem enter only times where there are units present.

After the data input process is finished, screen 2 will return. At this time the input file should be saved for later recalculation and/or updating. If this is not done at this time, the present risk calculations will destroy the data and they will not be available again. After saving the input file, run present risk (screen 4).

PRESENT RISK ANALYSIS
NUMBER OF FAILURES EXPECTED TO HAVE OCCURRED
BASED ON CURRENT OPERATING TIMES

WIDGET

ANALYSIS : J. L. BYERS

DATA PAIRS USED: (NO. OF UNITS, OPERATING TIME)

2, 1775, 1, 2225, 3, 2775, 12, 3225, 18, 3775, 19, 4225, 44, 4775, 41, 5225, 51, 5775, 33, 6225, 13, 6775, 3, 7225, 4, 8225, 1, 8775

NO. UNITS	TIME	%FAIL	NO. FAILS
2	1775	1.429319E-04	2.858639E-04
1	2225	3.569126E-04	3.569126E-04
3	2775	8.730888E-04	2.619267E-03
12	3225	1.604319E-03	1.925182E-02
18	3775	3.033936E-03	5.461085E-02
19	4225	4.78363E-03	9.088898E-02
44	4775	7.841349E-03	.3450193
41	5225	1.127422E-02	.462243
51	5775	1.686311E-02	.8600185
33	6225	2.278453E-02	.7518895
13	6775	3.195632E-02	.4154321
3	7225	4.126763E-02	.1238029
4	8225	6.877208E-02	.2750883
1	8775	8.845359E-02	8.845359E-02

TOTAL FAILURES = 3.489961

VALUE OF WEIBULL SLOPE BETA IS 4.051

VALUE OF CHARACTERISTIC LIFE ETA IS 15788

FIGURE 20: PRESENT RISK ANALYSIS SCREEN 4

NOTES:

1) % FAIL is the percentage of the number of units that should fail by the time started.
2) NO. FAILS is the product of % FAILS and NO. UNITS.
3) TOTAL FAILURES is the sum of the last column, NO. FAILS.

PROGRAM 7. FUTURE RISK ANALYSIS

This routine calculates the total number of units from a given population that are expected to fail during a specified future time period. The data input process is identical to that of the present risk analysis with two exceptions. The number of future months the analysis will cover is required along with the monthly utilization rate in hours per month over this time period. Of course, cycles or other life measurement units can be substituted for hours. The total future life is the product of the months and the monthly utilization rate. The warning and instructions for data input in present risk analysis apply here as well and will not be repeated. Input files created under present risk can be used by future risk as well.

FUTURE RISK ANALYSIS
4 NOV 87

YOU WILL NOW ENTER DATA DIRECTLY OR CREATE A FILE FOR LATER
UPDATING AND/OR RECALCULATING

YOU MAY ALSO RECALL AND UPDATE AN EXISTING FILE

PRESS ANY KEY TO CONTINUE

FIGURE 21: FUTURE RISK ANALYSIS SCREEN 1

SELECT FROM THE FOLLOWING:

1) CREATE A HISTOGRAM FILE
2) RETRIEVE A HISTOGRAM FILE
3) VERIFY A HISTOGRAM
4) EDIT A HISTOGRAM FILE
5) STORE YOUR HISTOGRAM FILE
6) RETURN TO FUTRISKS
7) QUIT

FIGURE 22: FUTURE RISK ANALYSIS SCREEN 2

```
    ENTER YOUR NAME & THE DATE: J. L. BYERS

    ENTER THE PART DESIGNATION: WIDGET

    ENTER FAILURE NAME - PART, COMPONENT, MODE, etc,: WEAR

    ENTER UNITS OF LIFE - HOURS, CYCLES, A/B LITES, etc.: HOURS

    ENTER YOUR HISTOGRAM (UNITS & TIME ON UNITS) HERE

    ENTER NUMBER OF UNITS WITH APPROXIMATELY THE SAME LIFE
    THEN ENTER TIME ON THESE UNITS (OR CYCLES, etc.)

    USE -99999 TO INDICATE END OF DATA
>
> 2
> 1775
> 1
> 2225
> 3
> 2775
> 12
> 3225
> 18
> 3775
> 19
> 4225
> 44
> 4775
> 41
> 5225
> 51
> 5775
> 33
> 6225
> 13
> 6775
>
```

FIGURE 23: FUTURE RISK ANALYSIS SCREEN 3

NOTES: After entering the histogram of failures and suspensions, screen 2 will reappear. At this time the input should be saved before proceeding with future risk calculations. It is especially important to do so for this routine since it is likely that several future time intervals will be examined. Each time future risk is run, the input file is destroyed by the calculations and it will be necessary to retrieve the stored data file before running the routine again.

FUTURE RISK ANALYSIS
FORECASTED FAILURES OVER THE NEXT 24 MONTHS TIME
UTILIZATION RATE IS 50 HOURS PER MONTH

WIDGET

ANALYSIS : J. L. BYERS

NO. UNITS	TIME	% FAIL	NO. FAILS	CUM FAILS
2	2975	0.00101	0.00203	0.00203
1	3425	0.00169	0.00169	0.00372
3	3975	0.00287	0.00860	0.01232
12	4425	0.00417	0.05003	0.06235
18	4975	0.00624	0.11228	0.17463
19	5425	0.00837	0.15906	0.33368
44	5975	0.01158	0.50961	0.84329
41	6425	0.01475	0.60475	1.44804
51	6975	0.01934	0.98654	2.43459
33	7425	0.02374	0.78336	3.21795
13	7975	0.02994	0.38923	3.60718
3	8425	0.03574	0.10721	3.71439
4	9425	0.05110	0.20441	3.91880
1	9975	0.06110	0.06110	3.97990

TOTAL FAILURES = 3.979902

BETA USED WAS : 4.051

ETA USED WAS : 15788

MONTHS WERE : 24

UTIL. RATE WAS : 50

FIGURE 24: FUTURE RISK ANALYSIS SCREEN 4

NOTES: The above is self explanatory. The last column is added to have the number of failures at any time desired. The last number is the same as the total failures for the analysis.

PROGRAM 8. CONFIDENCE INTERVAL CALCULATIONS FOR BETA AND ETA AND TIME TO FIRST FAILURE

This routine is composed of two codes. The first code calculates the confidence interval, or range of expected values for both BETA and ETA. The user chooses the confidence level of the results (0.99, 0.95, or 0.90). The higher the confidence level chosen, the wider the range of expected values the code will give, and vice versa. These ranges, or confidence intervals, are measures of the precision in estimating the parameters. The magnitude of the range is an indication of how far from the true value the estimate might deviate. These codes assume that the values of BETA and ETA entered are for a test sample where all units were run to failure.

Input data:

1) Confidence level to be used (0.99, 0.95, 0.90) (required)
2) Estimated value of BETA (required)
3) Estimated value of ETA (required)
4) Number of failures BETA and ETA are based on (required)

Output data:

1) Confidence interval (range) for BETA
2) Confidence interval (range) for ETA
3) Values of BETA and ETA used and confidence level chosen

The second code of this routine calculates the confidence interval for the time to first failure. A confidence level of 90% is assumed.

Input data:

1) Value of BETA to be used (required)
2) Value of ETA to be used (required)
3) Number of failures BETA and ETA are based on (required)
4) Estimated value of time to first failure
   (This value has no effect on the calculations) (optional)

Output data:

1) Confidence interval (range) for time to first failure
2) Estimated value of time to first failure (same as 4 above)

A quick estimate of time to first failure can be made using one of the following methods:

1. If A = the total number of units in the sample then -

   1/A x 100 = percentage of the total population represented by one unit

   Find this percentage on the Y-axis of the Weibull plot, observe where it intercepts the line through the data points, and read the corresponding hours on the X-axis.

The time read on the X-axis is an estimate of the time to first failure.

2. Another estimate might be obtained by adding the entries in the "NO. FAILS" column of the present risk analysis until a value nearest 1 is obtained. Read the corresponding number of hours in the "TIME" column to obtain the estimated time to first failure.

```
                    CONFIDENCE INTERVAL CALCULATION
                                 FOR
                   BETA - ETA - TIME TO FIRST FAILURE



WHICH CONFIDENCE LEVEL (0.99, 0.95, OR 0.90) DO YOU WISH TO USE TO
ESTABLISH A CONFIDENCE INTERVAL AROUND BETA AND ETA? .95


WHAT IS THE ESTABLISHED VALUE OF BETA? 4.051

WHAT IS THE ESTABLISHED OF ETA? 15788

WHAT NUMBER OF FAILURES ARE THESE VALUES OF BETA AND ETA BASED ON?4


THE CONFIDENCE INTERVALS, OR MEASUREMENT OF THE PRECISION OF THE
ESTIMATION OF BETA AND ETA ARE:

1.886199  <= BETA <= 8700355
                   12246.48 <= ETA  <= 20353.68


FOR BETA AND ETA ESTIMATES OF 3 AND 2000 AND A CONFIDENCE LEVEL OF
.95


*****************************************************************
```

FIGURE 25: CNFIN INTERVAL CALCULATION SCREEN 1

NOTES: Note that although the range of Beta and Eta are quite large, they were calculated under the assumption that only 4 (four) units were tested, and they were all tested to failure. As the number of units tested increases, so does the accuracy or certainty of the estimates of Beta and Eta.

```
YOU MAY NOW CALCULATE THE CONFIDENCE INTERVAL FOR THE TIME TO
FIRST FAILURE IF YOU HAVE CALCULATED THIS TIME TO FAIL PREVIOUSLY
IF YOU HAVE NOT CALCULATED THE TIME TO FIRST FAILURE YET, PROCEED
TO THE MENU.

    1. CALCULATE CONFIDENCE INTERVAL FOR TIME TO FIRST FAILURE.

    2. RETURN TO MENU.

    WHAT IS YOUR CHOICE?
```

FIGURE 26: CNFIN INTERVAL CALCULATION SCREEN 2

```
                    CONFIDENCE INTERVAL CALCULATION
                                 FOR
                         TIME TO FIRST FAILURE


VALUE OF BETA USED IS : 4.051

VALUE OF ETA USED IS : 15788

NUMBER OF FAILURES BETA AND ETA ARE BASED ON IS : 4

ESTIMATED (CALCULATED) VALUE OF TIME TO FIRST FAILURE IS : 6000
```

FIGURE 27: CNFIN INTERVAL CALCULATION SCREEN 3

```
    THE CONFIDENCE INTERVAL, OR MEASUREMENT OF PRECISION OF THE
    ESTIMATE OF THE TIME TO FIRST FAILURE IS :

         5417.87 <= TIME TO FIRST FAILURE <= 14699.21

    THE ESTIMATED VALUE OF TIME TO FIRST FAILURE IS : 6000
```

FIGURE 28: CNFIN INTERVAL CALCULATION SCREEN 4

PROGRAM 9. RELIABILITY AND CONFIDENCE INTERVAL FOR RELIABILITY

This routine contains two codes as the previous one did. The first code calculates the reliability of an item or part at any given time. The output consists of the reliability, probability of failure, and time at which they were calculated. The second code calculates the confidence interval for reliability. This is the range of expected values for reliability. As before, the user can select the confidence level (0.90, 0.95, or 0.99) at which the range will be calculated. The higher the confidence level chosen, the wider the interval that will be calculated. These codes assume that the values of BETA and ETA entered are for a test sample where all units were tested to failure.

Input Data (reliability code):

1) Value of BETA to be used	(required)
2) Value of ETA to be used	(required)
3) Time at which reliability is required	(required)

Output:

1) Reliability
2) Probability of failure
3) Values of BETA and ETA used

Input Data (confidence interval code):

1) Value of BETA to be used	(required)
2) Value of ETA to be used	(required)
3) Time at which confidence interval is desired	(required)
4) Sample size on BETA and ETA are based	(required)
5) Confidence level to be used (0.90, 0.95, 0.99)	(required)

Output:

1) Confidence interval for reliability

```
                    RELIABILITY
      CALCULATES RELIABILITY AS A FUNCTION OF TIME

INPUT THE VALUE OF BETA (WEIBULL SLOPE) TO USE? 4.051

INPUT THE VALUE OF BETA (CHARACTERISTIC LIFE) TO USE? 6000


THE RELIABILITY AT TIME 6000 IS .980341
THE PROBABILITY OF FAILURE AT THIS TIME IS 1.965904E-02


THE VALUES OF BETA AND ETA USED WERE 4.051 AND 15788

DO YOU WISH TO CALCULATE THE RELIABILITY FOR ANOTHER TIME
(ANSWER Y OR N) ?
```

FIGURE 29: CNFIN RELIABILITY CALCULATION SCREEN 1

```
THE RELIABILITY AT TIME 9000 IS .9024738
THE PROBABILITY OF FAILURE AT THIS TIME IS 9.752619E-02

THE VALUES OF BETA AND ETA USED WERE 4.051 AND 15788
```

FIGURE 30: CNFIN RELIABILITY CALCULATION SCREEN 2

```
CONFIDENCE INTERVAL CALCULATION
FOR
RELIABILITY
VERSION OF:  24 FEB 1987

INPUT THE VALUE OF BETA (WEIBULL SLOPE) TO USE? 4.051

INPUT THE VALUE OF ETA (CHARACTERISTIC LIFE) TO USE? 15788

INPUT THE TIME FOR WHICH YOU WANT THE CONFIDENCE INTERVAL
CALCULATED? 6000

INPUT THE SAMPLE SIZE ON WHICH BETA AND ETA ARE BASED? 245

WHICH CONFIDENCE LEVEL (0.99, 0.95, OR 0.90) DO YOU WISH TO USE
TO ESTABLISH A CONFIDENCE INTERVAL AROUND THE RELIABILITY? .95
```

FIGURE 31: CNFIN RELIABILITY CALCULATION SCREEN 3

```
.9663988 <= RELIABILITY <= .9885323
WHERE RELIABILITY IS .980341 FOR BETA = 4.051, ETA = 15788, AND
TIME = 6000
```

FIGURE 32: CNFIN RELIABILITY CALCULATION SCREEN 4

NOTES: The number of failures on which BETA and ETA are based affects the calculated reliability of the part or component. If the sample size is very small then statistically, the calculated values of BETA and ETA are probably not stabilized. This code assumes that the values of BETA and ETA entered are for a test sample where all units were tested to failure.

PROGRAM 10. WEIBULL FAILURE ANALYSIS - MONTE CARLO ANALYSIS

This is a complex code which uses Monte Carlo simulation techniques to analyze entire systems that are plagued with various failure modes. The user may want to identify the dominant failure modes and calculate the Weibull parameters using routine number one. In the absence of failure data to calculate these parameters, reasonable estimates may be obtained using routines number three and five (Historical Values of BETA (5) and Characteristic Life Calculation (3)).

With the Weibull parameters in hand, this code will forecast the number of failures for each system in a population as well as the times of failure during the user specified future time period. These calculations are repeated a number of times (iterations) in order to fulfill the statistical requirements of Monte Carlo analysis. The user should make at least ten (10) iterations in order to fulfill these requirements. The code will also require an inspection time interval for the system or component. When the system reaches this inspection time, it will be zero timed or made good-as-new (bad-as-new in some cases). If no inspection time is to be used in the maintenance system of the users system then the inspection period specified should be longer than the entire analytical time period. In this way the inspection period is never reached before the individual iterations are completed. If the system fails before reaching the end of the inspection period the code will assume that the system is repaired, all parts subject to the analysis made good-as-new, and put back in service. The failure times for each failure mode are calculated and the shortest time to failure is selected as the true failure time. If this failure time is less than the inspection time there will be a failure indication. Otherwise, there is no failure indication and the system goes to inspection with the current operating time being the previous time plus the inspection time limit. The analysis continues until the specified total future time is reached.

This routine is very computationally intensive and produces a very large output. The code limits the user to a maximum of twenty-five (25) systems per analysis. If more systems are to be analyzed, routines 11 and/or 12 can be used. Both of these routines have the same function as routine ten (10), but were specifically designed to analyze large numbers of systems. Routine 11 can analyze up to 250 systems, however, the output is greatly reduced and only the final tabulations of averages and total failures are printed. In addition only one failure mode at a time is analyzed. This may produce some error where there is a large interaction of failures, since a failure in one mode may precede, and thereby preclude, a failure in another mode prior to an inspection. If the first failure mode is not included in the analysis then there will be an error. This may be overcome if a representative sample of 25 or less can be analyzed that will be a true representation of a much larger sample. If not, then several analyses can be run to include all of the population through the appropriate representative samples. In the extreme case a special version of the number ten routine can be made available to analyze the correct number of systems. Routine twelve can accommodate over 1100 parts or systems, but only for one failure mode at a time. The same

comments as above are applicable. The output of routine twelve is reduced similar to that of routine eleven.

The input histogram files for routines eleven and twelve must be created using routine ten. This was done to reduce the total size of all three routines and is reasonable since all three routine use files of identical structure and input data. When creating an input file, if the time is zero for any system, then a zero must be entered for that system or group of systems.

These codes are very useful in that they can be used to determine the optimum service period for any system or component. Separate calculations can be made for a series of inspection intervals until a desired reliability requirement is met in terms of a number of failures allowed. These requirements might be the percentage of units that will be allowed to fail, or if a particular failure mode is to be absolutely avoided, the maximum operating time before this failure mode begins to be a factor can be determined. The latter requirement can be determined by inspecting the printed output of failure times for each failure mode, or by setting the inspection time lower and lower until there are no failures recorded for any iteration in an analysis with at least ten iterations, or more.

File Input Data:

1)	Name and date	(optional)
2)	System designation	(optional)
3)	Problem name	(optional)
4)	Units of life measurement	(optional)
5)	Histogram file (number of units & time on units)	(required)

Other Input Data:

1)	Number of data pairs entered in file	(required)
2)	Total number of systems in the sample	(required)
3)	Number of failure modes	(required)
4)	BETA for each failure mode	(required)
5)	ETA for each failure mode	(required)
6)	Number of future months the analysis will cover	(required)
7)	Operating hours or cycles per month	(required)
8)	Inspection interval	(required)
9)	System designation	(optional)
10)	Any number between +1 and +32767 (seed number for random number generator)	(required)
11)	Number of iterations to be performed	(required)

Output:

1) Summary of input
2) Total system hours or cycles
3) Cumulative time or cycles
4) Time to fail for each mode
5) Total number of failures per iteration

WEIBULL RISK
A MONTE CARLO SIMULATION

THIS PROGRAM PROVIDES THE CAPABILITY TO CALCULATE THE NUMBER OF FAILURES FOR SEVERAL DIFFERENT PARTS IN A SYSTEM OVER A USER SPECIFIED TIME PERIOD. UP TO 25 SYSTEMS CAN BE ANALYZED WITH SCHEDULED INSPECTIONS WHERE THE PARTS CONSIDERED ARE BROUGHT TO ZERO-TIME, i.e., ARE MADE GOOD-AS-NEW.

INPUTS CONSIST OF: NUMBER OF SYSTEMS; TIME SINCE LAST INSPECTION; ANALYTICAL TIME PERIOD; CYCLE OR HOUR UTILIZATION RATE; TIME BETWEEN INSPECTIONS, INITIAL TIME ON SYSTEMS; WEIBULL PARAMETERS (BETA & ETA); and SYSTEM DESIGNATION.

OUTPUT CONSISTS OF: TOTAL SYSTEM CYCLES OF HOURS; CUMULATIVE TIME OR CYCLES; TIME TO FAIL FOR EACH MODE; and TOTAL NUMBER OF FAILURES BY ITERATION.

TO CONTINUE INPUT 1 AND <ENTER>. TO QUIT INPUT -1 AND <ENTER>. YOUR CHOICE? 1

FIGURE 33: WEIBULL RISK SCREEN 1

THIS IS THE DATA INPUT SECTION OF THE WEIBULL RISK CODE.

YOU WILL BE ASKED TO INPUT VARIOUS DATA IN A GIVEN FORMAT.

THE FORMAT IS CRITICAL SO FOLLOW INSTRUCTIONS CAREFULLY.

TYPE Y <ENTER> TO INPUT DATA. TYPE Q <ENTER> TO QUIT? Y

FIGURE 34: WEIBULL RISK SCREEN 2

```
YOU WILL NOW ENTER DATA DIRECTLY OR CREATE A DATA FILE FOR
     LATER UPDATING AND/OR RECALCULATION

YOU MAY ALSO CHOOSE TO RECALL AND UPDATE AN EXISTING FILE

          PRESS ANY KEY TO CONTINUE
```

FIGURE 35: WEIBULL RISK SCREEN 3

```
     SELECT FROM THE FOLLOWING:

1) CREATE A HISTOGRAM FILE

2) RETRIEVE A HISTOGRAM FILE

3) VERIFY A HISTOGRAM FILE

4) EDIT A HISTOGRAM FILE

5) STORE YOUR HISTOGRAM FILE

6) RETURN TO WEIBRISK1

7) QUIT
```

FIGURE 36: WEIBULL RISK SCREEN 4

```
ENTER YOUR NAME & THE DATE: J. L. BYERS      09/27/88

ENTER THE SYSTEM DESIGNATION: MK-5

ENTER FAILURE PROBLEM NAME - PART, COMPONENT, MODE, etc.:
WIDGET WEAR - FAILURE

ENTER UNITS OF LIFE MEASUREMENT - HOURS, CYCLES, A/B LITES,
etc.: HOURS

     ENTER YOUR HISTOGRAM (UNITS & TIME ON UNITS) HERE

     ENTER NUMBER OF UNITS - THEN
          ENTER TIME ON UNITS

     USE -99999 TO INDICATE END OF DATA

> 2
> 155
> 1
> 276
> -99999
```

FIGURE 37: WEIBULL RISK SCREEN 5

NOTES: For this routine, an input file consisting of 3 systems will be used. Two failure modes are used and it is desired to know how many failures can be expected during the next twenty years. While this may seem extreme, it is not unusual in expensive, long lived equipment where re-engineering decisions must be made and costed out.

```
NOW INPUT THE NUMBER OF DATA PAIRS JUST ENTERED.? 2

INPUT THE TOTAL NUMBER OF SYSTEMS IN THE SAMPLE - NOT OVER 25.? 3

HOW MANY FAILURE MODES ARE THERE FOR THIS ANALYSIS? 2

INPUT BETA VALUE NUMBER 1 ? 4.051

INPUT BETA VALUE NUMBER 2 ? 3.0

INPUT ETA VALUE NUMBER 1 ? 15788

INPUT ETA VALUE NUMBER 2 ? 19629

INPUT THE NUMBER OF MONTHS THAT THIS ANALYSIS WILL COVER, i.e.,
36 FOR THREE YEARS.? 240

NEXT, INPUT THE OPERATING HOURS PER MONTH (AVERAGE) OVER THE TIME
PERIOD OF THIS ANALYSIS.? 50

INPUT THE INSPECTION INTERVAL FOR THE SYSTEM OF THIS ANALYSIS.?
6200

INPUT THE SYSTEM DESIGNATION.? MK-5

INPUT ANY NUMBER BETWEEN +1 AND + 32767 TO SEED THE RANDOM NUMBER
GENERATOR. USE A DIFFERENT NUMBER FOR EACH ANALYSIS.? 2964

LASTLY, INPUT THE NUMBER OF ITERATIONS TO BE PERFORMED DURING THE
ANALYSIS.? 10
```

FIGURE 38: WEIBULL RISK SCREEN 6

WEIBULL RISK ANALYSIS
A MONTE CARLO SIMULATION
WEIBRISK1

SYSTEM: MK-5

BETA VALUES:
4.051 3

ETA VALUES:
15788 19629

DATA PAIRS :

NO. SYST.	INIT. TIME
2	155
1	276

MAXIMUM OPERATING HOURS PER SYSTEM FROM THIS ANALYSIS IS 12000 HOURS

INSPECTION INTERVAL FOR THIS ANALYSIS IS 6200 HOURS

TIME DURATION OF THIS ANALYSIS IS 240 MONTHS

UTILIZATION RATE IS 50 HOURS PER SYSTEM PER MONTH

FIGURE 39: WEIBULL RISK SCREEN 7

NOTES:

A) Maximum operating time (MOT) per system is:
MOT=(monthly utilization rate)x(months of the analysis)

= (50) x (240)

= 12000 hours

B) Failure time for first failure is 5486.523 hours and occurs in iteration 4 on system number 1 (failure mode one).

C) Failure time for the second failure is 5928.713 hours and occurs in iteration 9 on system number 1 (failure mode one).

D) There were no failures in failure mode two in this analysis. Note however, that times are listed for each failure mode in order from left to right. Failure times less that the inspection time are not failures. The system is assumed to be operationally halted for inspection and marginal parts replaced. Other parts are certified good as new and deemed good enough to make it to the next inspection.

E) Once the time on any system passes the maximum operating time for the analysis, the analysis on that system is halted and the next system is started.

```
********************** DATA PAIR NUMBER 1 *********************

                    * * * ITERATION NUMBER 1 * * *

                              SYSTEM NUMBER 1

 19730.26      17606.24
TIME ON SYSTEM IS 6200
 17777.45 25020.63
TIME ON SYSTEM IS 12155
CUMULATIVE FAILURES FOR THIS DATA PAIR ARE 0
NUMBER OF FAILURES FOR SYSTEM  1 = 0

                              SYSTEM NUMBER 2

 12110.24      23837.24
TIME ON SYSTEM IS 6200
 17351.09      16471.52
TIME ON SYSTEM IS 12155
CUMULATIVE FAILURES FOR THIS DATA PAIR ARE 0
NUMBER OF FAILURES FOR SYSTEM  2 = 0

TOTAL FAILURES ITERATION NUMBER 1 = 0

                    * * * ITERATION NUMBER 2 * * *

                              SYSTEM NUMBER 1

 13355.3       13553.18
TIME ON SYSTEM IS 6200
 12894.66      10659.78
TIME ON SYSTEM IS 12155
CUMULATIVE FAILURES FOR THIS DATA PAIR ARE 0
NUMBER OF FAILURES FOR SYSTEM  1 = 0

                              SYSTEM NUMBER 2

 10139.67      20564.63
TIME ON SYSTEM IS 6200
 13300.2       18236.15
TIME ON SYSTEM IS 12155
CUMULATIVE FAILURES FOR THIS DATA PAIR ARE 0
NUMBER OF FAILURES FOR SYSTEM  2 = 0

TOTAL FAILURES ITERATION NUMBER 2 = 0

                    * * * ITERATION NUMBER 3 * * *

                              SYSTEM NUMBER 1

 15988.6       14206.04
TIME ON SYSTEM IS 6200
 13056.92      12865.66
TIME ON SYSTEM IS 12155
```

```
CUMULATIVE FAILURES FOR THIS DATA PAIR ARE 0
NUMBER OF FAILURES FOR SYSTEM  1 = 0

                              SYSTEM NUMBER 2

 20311.51      19067.72
TIME ON SYSTEM IS 6200
 12625.21      11042.74
TIME ON SYSTEM IS 12155
CUMULATIVE FAILURES FOR THIS DATA PAIR ARE 0
NUMBER OF FAILURES FOR SYSTEM  2 = 0

TOTAL FAILURES ITERATION  NUMBER 3 = 0

                    * * * ITERATION NUMBER 4 * * *

                              SYSTEM NUMBER 1

 6411.605      7892.794
TIME ON SYSTEM IS 6200
 5486.523      10986.68
TIME ON SYSTEM IS 11686.52
 10234.76      17962.42
TIME ON SYSTEM IS 12155
CUMULATIVE FAILURES FOR THIS DATA PAIR ARE1
NUMBER OF FAILURES FOR SYSTEM  1 = 1

                              SYSTEM NUMBER 2

 11374.15      24182.8
TIME ON SYSTEM IS 6200
 12565.94      19191.69
TIME ON SYSTEM IS 12155
CUMULATIVE FAILURES FOR THIS DATA PAIR ARE 1
NUMBER OF FAILURES FOR SYSTEM  2 = 0

TOTAL FAILURES ITERATION NUMBER 4 = 1

                    * * * ITERATION NUMBER 5 * * *

                              SYSTEM NUMBER 1

 14746.5       20031.81
TIME ON SYSTEM IS 6200
 6955.794      14486.71
TIME ON SYSTEM IS 12155
CUMULATIVE FAILURES FOR THIS DATA PAIR ARE 1
NUMBER OF FAILURES FOR SYSTEM 1  = 0

                              SYSTEM NUMBER 2

 8160.821      11458.36
TIME ON SYSTEM IS 6200
 12415.46      11297.66
TIME ON SYSTEM IS 12155
```

CUMULATIVE FAILURES FOR THIS DATA PAIR ARE 1
NUMBER OF FAILURES FOR SYSTEM 2 = 0

TOTAL FAILURES ITERATION NUMBER 5 = 0

* * * ITERATION NUMBER 6 * * *

SYSTEM NUMBER 1

17103.59 21936.56
TIME ON SYSTEM IS 6200
23084.51 12345.89
TIME ON SYSTEM IS 12155
CUMULATIVE FAILURES FOR THIS DATA PAIR ARE 1
NUMBER OF FAILURES FOR SYSTEM 1 = 0

SYSTEM NUMBER 2

15826.27 13212.17
TIME ON SYSTEM IS 6200
10881.04 19549.08
TIME ON SYSTEM IS 12155
CUMULATIVE FAILURES FOR THIS DATA PAIR ARE 1
NUMBER OF FAILURES FOR SYSTEM 2 = 0

TOTAL FAILURES ITERATION NUMBER 6 = 0

* * * ITERATION NUMBER 7 * * *

SYSTEM NUMBER 1

15132.42 12874.17
TIME ON SYSTEM IS 6200
10068.55 14407.17
TIME ON SYSTEM IS 12155
CUMULATIVE FAILURES FOR THIS DATA PAIR ARE 1
NUMBER OF FAILURES FOR SYSTEM 1 = 0

SYSTEM NUMBER 2

8238.55 12017.47
TIME ON SYSTEM IS 6200
9970.696 30407.44
TIME ON SYSTEM IS 12155
CUMULATIVE FAILURES FOR THIS DATA PAIR ARE 1
NUMBER OF FAILURES FOR SYSTEMS 2 = 0

TOTAL FAILURES ITERATION NUMBER 7 = 0

* * * ITERATION NUMBER 8 * * *

SYSTEM NUMBER 1

14141.09 11727.99
TIME ON SYSTEM IS 6200

```
 18339.03       11068.12
TIME ON SYSTEM IS 12155
CUMULATIVE FAILURES FOR THIS DATA PAIR ARE 1
NUMBER OF FAILURES FOR SYSTEM  1 = 0

                              SYSTEM NUMBER 2

 12533.83       19670.73
TIME ON SYSTEM IS 6200
 17340.48       24735.75
TIME ON SYSTEM IS 12155
CUMULATIVE FAILURES FOR THIS DATA PAIR ARE 1
NUMBER OF FAILURES FOR SYSTEM  2 = 0

TOTAL FAILURES ITERATION NUMBER 8 = 0

                    * * * ITERATION NUMBER 9 * * *

                              SYSTEM NUMBER 1

 5928.713       15926.89
TIME ON SYSTEM IS 5928.713
 8948.174       10385.44
TIME ON SYSTEM IS 12128.71
 16391.06       11774.59
TIME ON SYSTEM IS 12155
CUMULATIVE FAILURES FOR THIS DATA PAIR ARE 2
NUMBER OF FAILURES FOR SYSTEM  1 = 1

                              SYSTEM NUMBER 2

 15898.09       8670.119
TIME ON SYSTEM IS 6200
 12762.26       38743.03
TIME ON SYSTEM IS 12155
CUMULATIVE FAILURES FOR THIS DATA PAIR ARE 2
NUMBER OF FAILURES FOR SYSTEM  2 = 0

TOTAL FAILURES ITERATION NUMBER 9 = 1

                    * * * ITERATION NUMBER 10 * * *

                              SYSTEM NUMBER 1

 10070.3        6905.741
TIME ON SYSTEM IS 6200
 11896.66       6914.634
TIME ON SYSTEM IS 12155
CUMULATIVE FAILURES FOR THIS DATA PAIR ARE 2
NUMBER OF FAILURES FOR SYSTEM  1 = 0
```

```
                    SYSTEM NUMBER 2

 17627.27      7635.582
TIME ON SYSTEM IS 6200
 16144.44      23078.36
TIME ON SYSTEM IS 12155
CUMULATIVE FAILURES FOR THIS DATA PAIR ARE 2
NUMBER OF FAILURES FOR SYSTEM  2 = 0

TOTAL FAILURES ITERATION NUMBER 10 = 0


AVERAGE NUMBER FAILURES 10 ITERATIONS = .2

NUMBER OF FAILURES IN ITERATION 1 = 0

NUMBER OF FAILURES IN ITERATION 2 = 0

NUMBER OF FAILURES IN ITERATION 3 = 0

NUMBER OF FAILURES IN ITERATION 4 = 1

NUMBER OF FAILURES IN ITERATION 5 = 0

NUMBER OF FAILURES IN ITERATION 6 = 0

NUMBER OF FAILURES IN ITERATION 7 = 0

NUMBER OF FAILURES IN ITERATION 8 = 0

NUMBER OF FAILURES IN ITERATION 9 = 1

NUMBER OF FAILURES IN ITERATION 10 = 0

AVERAGE NUMBER OF FAILURES FOR SYSTEM  1 IS .2
AVERAGE NUMBER OF FAILURES FOR SYSTEM  2 IS 0
```

```
********************** DATA PAIR NUMBER 2 *********************

                    * * * ITERATION NUMBER 1 * * *

                              SYSTEM NUMBER 1

 20387.96      18464.85
TIME ON SYSTEM IS 6200
 14627.4       14906.99
TIME ON SYSTEM IS 12276
CUMULATIVE FAILURES FOR THIS DATA PAIR ARE 0
NUMBER OF FAILURES FOR SYSTEM  1 = 0


TOTAL FAILURES FOR ITERATION NUMBER 1 = 0


                    * * * ITERATION NUMBER 2 * * *

                              SYSTEM NUMBER 1

 10736.76      14955.86
TIME ON SYSTEM IS 6200
 17422.33      27950.8
TIME ON SYSTEM IS 12276
CUMULATIVE FAILURES FOR THIS DATA PAIR ARE 0
NUMBER OF FAILURES FOR SYSTEM  1 = 0


TOTAL FAILURES FOR ITERATION NUMBER 2 = 0

                    * * * ITERATION NUMBER 3 * * *

                              SYSTEM NUMBER 1

 15546.05      22573.97
TIME ON SYSTEM IS 6200
 16540.19      23489.39
TIME ON SYSTEM IS 12276
CUMULATIVE FAILURES FOR THIS DATA PAIR ARE 0
NUMBER OF FAILURFS FOR SYSTEM  1 = 0


TOTAL FAILURES FOR ITERATION NUMBER 3 = 0

                    * * * ITERATION NUMBER 4 * * *

                              SYSTEM NUMBER 1
```

```
 11854.65      11747.13
TIME ON SYSTEM IS 6200
 14875.41      14072.17
TIME ON SYSTEM IS 12276
CUMULATIVE FAILURES FOR THIS DATA PAIR ARE 0
NUMBER OF FAILURES FOR SYSTEM  1 = 0


TOTAL FAILURES ITERATION NUMBER 4 = 0

                    * * * ITERATION NUMBER 5 * * *

                              SYSTEM NUMBER 1

 2028.952      20120.71
TIME ON SYSTEM IS 2028.952
 13520.98      10546.84
TIME ON SYSTEM IS 8228.952
 13514.63      26459.95
CUMULATIVE FAILURES FOR THIS DATA PAIR ARE 1
NUMBER OF FAILURES FOR SYSTEM 1  = 1

TOTAL FAILURES ITERATION NUMBER  5 = 1

                    * * * ITERATION NUMBER 6 * * *

                              SYSTEM NUMBER 1

 13626.45      7077.893
TIME ON SYSTEM IS 6200
 10275.11      18322.2
TIME ON SYSTEM IS 12276
CUMULATIVE FAILURES FOR THIS DATA PAIR ARE 1
NUMBER OF FAILURES FOR SYSTEM 1 = 0


TOTAL FAILURES ITERATION NUMBER 6 = 0

                    * * * ITERATION NUMBER 7 * * *

                              SYSTEM NUMBER 1

 8653.121      18169.36
TIME ON SYSTEM IS 6200
 13985.53      17545.27
TIME ON SYSTEM IS 12276
CUMULATIVE FAILURES FOR THIS DATA PAIR ARE 1
NUMBER OF FAILURES FOR SYSTEM  1 = 0


TOTAL FAILURES ITERATION NUMBER 7 = 0

                    * * * ITERATION NUMBER 8 * * *
```

```
                              SYSTEM NUMBER 1

 20393.76      8329.997
TIME ON SYSTEM IS 6200
 18362.31      21305.9
TIME ON SYSTEM IS 12276
CUMULATIVE FAILURES FOR THIS DATA PAIR ARE 1
NUMBER OF FAILURES FOR SYSTEM  1 = 0


TOTAL FAILURES ITERATION NUMBER 8 = 0

                    * * * ITERATION NUMBER 9 * * *

                              SYSTEM NUMBER 1

 14072.96      13317
TIME ON SYSTEM IS 6200
 10791.42      9723.451
TIME ON SYSTEM IS 12276
CUMULATIVE FAILURES FOR THIS DATA PAIR ARE 1
NUMBER OF FAILURES FOR SYSTEM  1 = 0


TOTAL FAILURES ITERATION NUMBER 9 = 0

                    * * * ITERATION NUMBER 10 * * *

                              SYSTEM NUMBER 1

 10917.27      18612.29
TIME ON SYSTEM IS 6200
 24167.96      22853.67
TIME ON SYSTEM IS 12276
CUMULATIVE FAILURES FOR THIS DATA PAIR ARE 1
NUMBER OF FAILURES FOR SYSTEM  1 = 0

TOTAL FAILURES ITERATION NUMBER 10 = 0


AVERAGE NUMBER FAILURES 10 ITERATIONS = .1

NUMBER OF FAILURES IN ITERATION 1 = 0

NUMBER OF FAILURES IN ITERATION 2 = 0

NUMBER OF FAILURES IN ITERATION 3 = 0

NUMBER OF FAILURES IN ITERATION 4 = 0

NUMBER OF FAILURES IN ITERATION 5 = 1

NUMBER OF FAILURES IN ITERATION 6 = 0

NUMBER OF FAILURES IN ITERATION 7 = 0
```

NUMBER OF FAILURES IN ITERATION 8 = 0

NUMBER OF FAILURES IN ITERATION 9 = 0

NUMBER OF FAILURES IN ITERATION 10 = 0

AVERAGE NUMBER OF FAILURES FOR SYSTEM 1 IS .1

PROGRAM 11. WEIBULL FAILURE ANALYSIS - SHORT PRINTOUT

This routine has the same function as routine ten with the following exceptions:

1. Up to 250 systems or components can be analyzed.
2. Only one failure mode at a time may be analyzed.
3. Output is reduced and only a summary of the results are printed.

Note that the input histogram for this routine "must" be created using routine ten (10).

WEIBULL RISK
'SHORT'
A MONTE CARLO SIMULATION

THIS PROGRAM PROVIDES THE CAPABILITY TO CALCULATE THE NUMBER OF FAILURES DUE TO A SINGLE FAILURE MODE IN A SYSTEM OVER A USER SPECIFIED TIME PERIOD. UP TO 250 SYSTEMS CAN BE ANALYZED WITH SCHEDULED INSPECTIONS WHERE THE PARTS CONSIDERED ARE BROUGHT TO ZERO-TIME, i.e., ARE MADE GOOD-AS-NEW.

INPUTS CONSIST OF: NUMBER OF SYSTEMS; TIME SINCE LAST INSPECTION; ANALYTICAL TIME PERIOD; MONTHLY UTILIZATION RATE; TIME BETWEEN INSPECTIONS, INITIAL TIME ON SYSTEMS; WEIBULL PARAMETERS (BETA & ETA); and SYSTEM DESIGNATION.

OUTPUT CONSISTS OF TOTAL NUMBER OF FAILURES BY ITERATION AND AVERAGES PER SYSTEM AND ITERATION.

TO CONTINUE INPUT 1 AND <ENTER>. TO QUIT INPUT -1 AND <ENTER>. YOUR CHOICE?

FIGURE 40: WEIBULL SHORT RISK SCREEN 1

THIS IS THE DATA INPUT SECTION OF THE WEIBULL RISK CODE <SHORT VERSION>.

YOU WILL BE ASKED TO INPUT VARIOUS DATA IN A GIVEN FORMAT.

THE FORMAT IS CRITICAL SO FOLLOW INSTRUCTIONS CAREFULLY.

TYPE 1 <ENTER> TO INPUT DATA. TYPE -1 <ENTER> TO QUIT.
YOUR CHOICE?

FIGURE 41: WEIBULL SHORT RISK SCREEN 2

YOU WILL NOW RETRIEVE DATA FROM A N EXISTING FILE

PRESS <ENTER > KEY TO CONTINUE

FIGURE 42: WEIBULL SHORT RISK SCREEN 3

```
NOW INPUT THE NUMBER OF DATA PAIRS JUST ENTERED.? 2

INPUT THE TOTAL NUMBER OF SYSTEMS IN THE SAMPLE - NOT OVER 250?.3

INPUT THE VALUE OF BETA? 4.051

INPUT THE VALUE OF ETA? 15788

INPUT THE NUMBER OF MONTHS THAT THIS ANALYSIS WILL COVER, i.e.,
36 MONTHS FOR THREE YEARS.? 240

NEXT, INPUT THE OPERATING HOURS PER MONTH (AVERAGE) OVER THE TIME
PERIOD OF THIS ANALYSIS.? 50

INPUT THE INSPECTION INTERVAL FOR THE SYSTEM OF THIS ANALYSIS.?
6200

INPUT THE SYSTEM DESIGNATION.? MK-5

INPUT ANY NUMBER BETWEEN +1 AND + 32767 TO SEED  THE RANDOM
NUMBER GENERATOR. USE A DIFFERENT NUMBER FOR EACH ANALYSIS? 11846

LASTLY, INPUT THE NUMBER OF ITERATIONS TO BE PERFORMED DURING THE
ANALYSIS.? 10
```

FIGURE 43: WEIBULL SHORT RISK SCREEN 4

WEIBULL RISK ANALYSIS
A MONTE CARLO SIMULATION
SHTWEIB2
SYSTEM: MK-5

BETA VALUES: 4.051

ETA VALUES: 15788

DATA PAIRS:

NO. SYST.	INIT. TIME
2	155
1	276

MAXIMUM OPERATING HOURS PER SYSTEM FOR THIS ANALYSIS IS 12000 HRS

INSPECTION INTERVAL FOR THIS ANALYSIS IS 6200 HOURS

TIME DURATION OF THIS ANALYSIS IS 240 MONTHS

UTILIZATION RATE IS 50 HOURS PER SYSTEM PER MONTH

FIGURE 44: WEIBULL SHORT RISK SCREEN 5

```
OUTPUT:

********************** DATA PAIR NUMBER 1 *********************

AVERAGE NUMBER FAILURES 10 ITERATIONS = .2

NUMBER OF FAILURES IN ITERATION 1 = 0

NUMBER OF FAILURES IN ITERATION 2 = 0

NUMBER OF FAILURES IN ITERATION 3 = 0

NUMBER OF FAILURES IN ITERATION 4 = 0

NUMBER OF FAILURES IN ITERATION 5 = 1

NUMBER OF FAILURES IN ITERATION 6 = 0

NUMBER OF FAILURES IN ITERATION 7 = 0

NUMBER OF FAILURES IN ITERATION 8 = 0

NUMBER OF FAILURES IN ITERATION 9 = 1

NUMBER OF FAILURES IN ITERATION 10 = 0

AVERAGE NUMBER OF FAILURES FOR SYSTEM  1 IS .1
AVERAGE NUMBER OF FAILURES FOR SYSTEM  2 IS .1
```

```
OUTPUT, CONT:

********************** DATA PAIR NUMBER 2 *********************


AVERAGE NUMBER FAILURES 10 ITERATIONS = .1

NUMBER OF FAILURES IN ITERATION 1 = 0

NUMBER OF FAILURES IN ITERATION 2 = 0

NUMBER OF FAILURES IN ITERATION 3 = 0

NUMBER OF FAILURES IN ITERATION 4 = 0

NUMBER OF FAILURES IN ITERATION 5 = 1

NUMBER OF FAILURES IN ITERATION 6 = 0

NUMBER OF FAILURES IN ITERATION 7 = 0

NUMBER OF FAILURES IN ITERATION 8 = 1

NUMBER OF FAILURES IN ITERATION 9 = 0

NUMBER OF FAILURES IN ITERATION 10 = 0

AVERAGE NUMBER OF FAILURES FOR SYSTEM  1 IS .1
```

PROGRAM 12. WEIBULL FAILURE ANALYSIS - FOR OVER 1100 SYSTEM/PARTS

This routine is another variation of routine ten. It has the ability to analyze over 1100 parts, but only one failure mode at a time. Again, the output is reduced to a summary of the results and the input histogram must be created using routine ten.

```
                    WEIBULL RISK
                     'BIGWEIBL'
              A MONTE CARLO SIMULATION

     THIS PROGRAM PROVIDES THE CAPABILITY TO CALCULATE THE NUMBER OF
FAILURES DUE TO A SINGLE FAILURE MODE IN A SYSTEM OVER A USER
SPECIFIED TIME PERIOD. UP TO 1100 SYSTEMS CAN BE ANALYZED.

TO CONTINUE INPUT 1 AND <ENTER>. TO QUIT INPUT -1 AND <ENTER>.  YOUR
CHOICE?
```

FIGURE 45: BIG WEIBULL RISK SCREEN 1

```
     YOU WILL NOW RETRIEVE DATA FROM A N EXISTING FILE

               PRESS <ENTER> KEY TO CONTINUE
```

FIGURE 46: BIG WEIBULL RISK SCREEN 2

```
     ENTER THE NAME OF THE FILE TO BE RETRIEVED MANUALMC
```

FIGURE 47: BIG WEIBULL RISK SCREEN 3

WEIBULL RISK ANALYSIS
A MONTE CARLO SIMULATION
BIGWEIBL
SYSTEM: MK-5

BETA VALUES : 4.051

ETA VALUES : 15788

DATA PAIRS :

NO. SYST.	INIT. TIME
2	155
1	276

MAXIMUM OPERATING HOURS PER SYSTEM FOR THIS ANALYSIS IS 12000 HRS

INSPECTION INTERVAL FOR THIS ANALYSIS IS 6200 HOURS

TIME DURATION OF THIS ANALYSIS IS 240 MONTHS

UTILIZATION RATE IS 50 HOURS PER SYSTEM PER MONTH

FIGURE 48: BIG WEIBULL RISK SCREEN 4

```
OUTPUT:

********************** DATA PAIR NUMBER 1 *********************


AVERAGE NUMBER FAILURES 10 ITERATIONS = .1


NUMBER OF FAILURES IN ITERATION 1 = 0
THE AVERAGE NUMBER OF FAILURES PER SYSTEM IS 0

NUMBER OF FAILURES IN ITERATION 2 = 0
THE AVERAGE NUMBER OF FAILURES PER SYSTEM IS 0

NUMBER OF FAILURES IN ITERATION 3 = 0
THE AVERAGE NUMBER OF FAILURES PER SYSTEM IS 0

NUMBER OF FAILURES IN ITERATION 4 = 0
THE AVERAGE NUMBER OF FAILURES PER SYSTEM IS 0

NUMBER OF FAILURES IN ITERATION 5 = 1
THE AVERAGE NUMBER OF FAILURES PER SYSTEM IS 0

NUMBER OF FAILURES IN ITERATION 6 = 0
THE AVERAGE NUMBER OF FAILURES PER SYSTEM IS 0

NUMBER OF FAILURES IN ITERATION 7 = 0
THE AVERAGE NUMBER OF FAILURES PER SYSTEM IS 0

NUMBER OF FAILURES IN ITERATION 8 = 1
THE AVERAGE NUMBER OF FAILURES PER SYSTEM IS .5

NUMBER OF FAILURES IN ITERATION 9 = 0
THE AVERAGE NUMBER OF FAILURES PER SYSTEM IS 0

NUMBER OF FAILURES IN ITERATION 10 = 0
THE AVERAGE NUMBER OF FAILURES PER SYSTEM IS 0
```

OUTPUT, CONT:

********************* DATA PAIR NUMBER 2 *********************

AVERAGE NUMBER FAILURES 10 ITERATIONS = .1

NUMBER OF FAILURES IN ITERATION 1 = 0
THE AVERAGE NUMBER OF FAILURES PER SYSTEM IS 0

NUMBER OF FAILURES IN ITERATION 2 = 0
THE AVERAGE NUMBER OF FAILURES PER SYSTEM IS 0

NUMBER OF FAILURES IN ITERATION 3 = 0
THE AVERAGE NUMBER OF FAILURES PER SYSTEM IS 0

NUMBER OF FAILURES IN ITERATION 4 = 0
THE AVERAGE NUMBER OF FAILURES PER SYSTEM IS 0

NUMBER OF FAILURES IN ITERATION 5 = 1
THE AVERAGE NUMBER OF FAILURES PER SYSTEM IS 0

NUMBER OF FAILURES IN ITERATION 6 = 0
THE AVERAGE NUMBER OF FAILURES PER SYSTEM IS 0

NUMBER OF FAILURES IN ITERATION 7 = 0
THE AVERAGE NUMBER OF FAILURES PER SYSTEM IS 0

NUMBER OF FAILURES IN ITERATION 8 = 0
THE AVERAGE NUMBER OF FAILURES PER SYSTEM IS 0

NUMBER OF FAILURES IN ITERATION 9 = 0
THE AVERAGE NUMBER OF FAILURES PER SYSTEM IS 0

NUMBER OF FAILURES IN ITERATION 10 = 1
THE AVERAGE NUMBER OF FAILURES PER SYSTEM IS 1

PROGRAM 13. ZERO FAILURE TEST TIME REQUIREMENTS FOR SUBSTANTIATION TESTS

This code establishes a test program, which if passed, represents substantiation that an engineering change or fix has eliminated a particular failure mode. In order for the test program to be passed, no units are permitted to fail. If a unit fails, the test program is not successful. Two test programs approaches are available.

Approach Number One:

With this approach the user specifies the duration of test time for each test article and the code returns the number of required test articles that must successfully complete the test in order to statistically determine that the failure mode has been eliminated or significantly improved.

Input data:

1) Weibull slope BETA (required)
2) Characteristic life ETA (required)
3) Test hour approximation (required)

Output:

1) Number of articles to be tested for the duration of given test time (required)

Approach Number Two:

This approach require the user to input an estimate of the number of articles to be tested and the code will return with the test time that each article must survive without failure in order to statistically determine that the failure mode has been eliminated.

Input data:

1) Weibull slope BETA (required)
2) Characteristic life ETA (required)
3) Number of articles to be tested (required)

Output:

1) Test time that each article must survive without failure

```
NUMBER OF TEST UNITS AND TEST TIME FOR EACH

VERSION: 17 MAY 87

THIS CODE CALCULATES  THE STATISTICAL REQUIREMENT FOR SUBSTANTIATION
TESTING THAT DEMONSTRATES A REDESIGNED PART / SYSTEM HAS ELIMINATED
OR SIGNIFICANTLY IMPROVED A KNOWN FAILURE MODE - BETA AND ETA ARE
ASSUMED TO BE KNOWN.

THE RESULTING TEST PLAN GIVES:
          1. THE REQUIRED NUMBER OF TEST UNITS
          2. TEST TIME TO BE ACCUMULATED ON EACH UNIT
FIFTY (50) IS THE UPPER LIMIT OF TEST UNITS AND TEST TIME EXPRESSED
AS A FRACTION OF THE CHARACTERISTIC LIFE, ETA.
               RATIO = (TEST TIME)/(CHARACTERISTIC LIFE)
                                 OR
               TEST TIME = RATIO * CHARACTERISTIC LIFE

INPUT THE WEIBULL SLOPE BETA (BETA <=5.0 ONLY) FOR THE FAILURE MODE?
4.051
INPUT THE CHARACTERISTIC LIFE ETA? 15788
```

FIGURE 49: ZERO FAIL TEST PROGRAM SCREEN 1

```
USUALLY A TEST PROGRAM IS DRIVEN BY A PRACTICAL LEVEL OF TEST TIME
WHICH IS VERY EXPENSIVE.

MAKE AN ESTIMATE OF A REASONABLE TEST TIME, RECOGNIZING THAT AT
LEAST THREE (3) UNITS OR MORE MUST EACH BE TESTED FOR THAT TIME

INPUT TEST HOURS?  6000

RATIO = .3800355         BETA = 4.051

NOW CHOOSE THE NEAREST VALUE OF THE SLOPE BETA AND RATIO OF TEST
TIME TO THE CHARACTERISTIC LIFE THAT IS IN THE FOLLOWING TABLE. MAKE
A NOTE OF THE SAMPLE SIZE FROM THE TABLE.

PRESS ENTER TO CONTINUE?
```

FIGURE 50: ZERO FAIL TEST PROGRAM SCREEN 2

NOTES: The values of RATIO and BETA will be used in the table that follows on the next screen. The table is used to determine the number of units to be tested as a function of the test hours chosen and the value of BETA. The first row of the table are values of BETA and the first column are values of RATIO.

RATIO	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
0.01	24	**	**	**	**	**	**	**	**	**
0.02	17	**	**	**	**	**	**	**	**	**
0.03	14	**	**	**	**	**	**	**	**	**
0.04	12	**	**	**	**	**	**	**	**	**
0.05	11	47	**	**	**	**	**	**	**	**
0.06	10	39	**	**	**	**	**	**	**	**
0.07	9	33	**	**	**	**	**	**	**	**
0.08	9	29	**	**	**	**	**	**	**	**
0.09	8	26	**	**	**	**	**	**	**	**
0.10	8	24	**	**	**	**	**	**	**	**
0.20	6	12	26	**	**	**	**	**	**	**
0.30	5	8	15	26	47	**	**	**	**	**
0.40	4	6	10	15	23	36	**	**	**	**
0.50	4	5	7	10	14	19	27	37	**	**
0.60	3	4	5	7	9	11	14	18	23	30
0.70	3	4	4	5	6	7	9	10	12	14
0.80	3	3	4	4	5	5	6	6	7	8
0.90	3	3	3	3	3	4	4	4	4	4
1.00	3	3	3	3	3	3	3	3	3	3

** INDICATES SAMPLE SIZE EXCEEDS 50-INPUT 99 FOR SAMPLE SIZE
BETA = 4.051 RATIO = .3800355

PRINT SCREEN FOR HARD COPY OF THE TABLE. INPUT THE SAMPLE SIZE FROM THE TABLE?

FIGURE 51: ZERO FAIL TEST PROGRAM SCREEN 3

```
                    SAMPLE SIZE = 99

IF A REASONABLE RATIO TEST TIME TO ETA HAS RESULTED IN AN
UNREASONABLE SAMPLE SIZE (OR A SAMPLE SIZE OF OVER FIFTY, INDICATED
BY **) YOU SHOULD NOW MAKE ANOTHER ESTIMATE OF TEST HOURS OR OPT
FOR ANOTHER METHOD TEST PLAN DETERMINATION.

PLEASE CHOOSE FROM THE FOLLOWING OPTIONS:

*****   SINCE SAMPLE SIZE IS 99 CHOOSE ONLY OPTION 2 OR 3   *****

TO CONTINUE PRESS ENTER?

         1. DISPLAY THE TEST PLAN FOR CURRENT SAMPLE SIZE OF 99

         2. MAKE ANOTHER ESTIMATE OF TEST HOURS.

         3. USE ALTERNATE TEST PLAN METHOD.

INPUT OPTION NUMBER FROM THE ABOVE LIST.? 3
```

FIGURE 52: ZERO FAIL TEST PROGRAM SCREEN 4

NOTES: This routine allows a maximum number of 50 units to be tested. For the values of RATIO and BETA in this sample problem,the table shows that more than 50 units will be required (indicated by **). Therefore, another value of test hours must be chosen (higher value) or the alternate test plan method must be used. Choosing a higher value of test hours will reduce the no. required but is an iterative process. Option 3 will be used. Here the number of units to be tested is chosen. A value of 3 will result in the minimum number of units which is desirable when test articles are expensive.

```
THE ALTERNATE TEST PLAN METHOD REQUIRES THE INPUT OF A REASONABLE
NUMBER OF UNITS FOR TEST (SAMPLE SIZE) AND THE SELECTION OF A TEST
HOUR RATIO FROM THE FOLLOWING TABLE. MAKE AN ESTIMATE OF A
REASONABLE SAMPLE SIZE? 12

NOW CHOOSE THE NEAREST VALUE OF THE WEIBULL SLOPE BETA AND THE
SAMPLE SIZE YOU JUST ESTIMATED AND THEN NOTE THE CORRESPONDING TEST
HOUR RATIO.

PRESS ENTER TO CONTINUE.
```

FIGURE 53: ZERO FAIL TEST PROGRAM SCREEN 5

BETA

SAMPLE SIZE	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
3	.589	.767	.838	.876	.900	.916	.927	.936	.943	.948
4	.331	.576	.692	.759	.802	.832	.854	.871	.884	.895
5	.212	.460	.596	.679	.733	.772	.801	.824	.842	.856
6	.147	.384	.528	.619	.682	.727	.761	.787	.808	.826
7	.108	.329	.477	.574	.641	.690	.728	.757	.781	.801
8	.083	.288	.436	.536	.608	.660	.701	.732	.758	.780
9	.065	.256	.403	.506	.580	.635	.677	.711	.739	.761
10	.053	.230	.376	.480	.556	.613	.657	.693	.722	.745
12	.037	.192	.333	.438	.517	.577	.624	.662	.693	.719
14	.027	.164	.300	.406	.486	.548	.597	.637	.670	.697
16	.021	.144	.275	.379	.461	.524	.575	.616	.650	.679
18	.016	.128	.254	.358	.439	.504	.556	.598	.633	.663
20	.013	.115	.237	.339	.421	.486	.539	.582	.619	.649
25	.008	.092	.204	.303	.385	.452	.506	.551	.589	.621
30	.006	.077	.181	.277	.358	.425	.480	.526	.565	.598
40	.003	.058	.149	.240	.319	.386	.442	.490	.530	.565
50	.002	.046	.128	.215	.292	.358	.415	.463	.505	.540

BETA = 4.051 SAMPLE = 12

PRINT SCREEN FOR HARD COPY OF TABLE. INPUT TEST HOUR RATIO FROM TABLE? .662

FIGURE 54: ZERO FAIL ALTERNATE PLAN TABLE SCREEN 6

```
THE TEST PLAN NOW CONSISTS OF THE FOLLOWING:

                    SAMPLE SIZE 12

                    TEST HOURS ARE 10541.66

IF ALL THE SAMPLES SURVIVE THE TEST WITHOUT FAILURE THEN THE
FAILURE MODE WHERE

               BETA = 4.051   AND    ETA = 15788
HAS BEEN EITHER ELIMINATED OR SIGNIFICANTLY IMPROVED.
THE TEST TIME IS 66.2 PERCENT OF THE CHARACTERISTIC LIFE OF
15788 HOURS.
```

FIGURE 55: ZERO FAIL TEST PROGRAM SCREEN 7

NOTES: It is important to note that as BETA decreases, the test hours required decreases as well. As the sample size increases the test hours required decrease also. The actual choices that are made are really a function of the cost of test articles and the cost of running the test.

PROGRAM 14. NON-ZERO FAILURE TEST PLAN GENERATION

This routine calculates the number of units that must be tested during a user specified test time in order to show that a failure mode has been eliminated or significantly improved. Unlike the previous routine, some units may be allowed to fail and the test plan results could be considered successful. This maximum number of failures is also provided.

The user first inputs the probability of passing the test without a fix. This should be a low number such as 0.10 since the chances of a successful test without making a fix are very small. The second input consists of the probability of passing the test if a good fix is made for the failure mode in question. This should be a high probability such as 0.90. In any case, the sum of these two probabilities should always be 1.0.

Part of the output consists of the maximum number of test hours that would be run if there were no test failures (100% success rate). This number should be used as an indication of whether the test is too long by considering the cost per test hour, the cost of the test articles, manpower costs, etc. If the required number of test units given by the code is too large, it may be necessary to increase the test time for each unit. Several iterations can be conducted until a good compromise is reached.

Input data (all required):

1) A0 or the probability of passing the test with ETA of the failure mode - usually 0.10.
2) A1 or the probability of passing the test with the ETA desired after a good fix - usually 0.90.
3) Value of ETA for the failure mode.
4) Value of ETA after a good fix (desired value).
5) Number of test hours or cycles for each test article.
6) Value of BETA for the failure mode.

Output:

1) Size of test sample required.
2) Number of test articles allowed to fail.
3) Maximum test hours if all units were run without failure.

```
          PROGRAM TO GENERATE A NON-ZERO FAILURE TEST PLAN
             SAMPLE SIZE REQUIRED FOR GIVEN TEST TIME


THESE TEST PLANS WILL HAVE THE FOLLOWING STRUCTURE:

          A. PUT N ITEMS ON TEST FOR T HOURS (CYCLES) EACH.
          B. WHEN AN ITEM ON TEST FAILS, IT IS NOT REPAIRED.
          C. IF R0 OR FEWER FAILURES OCCUR, THE TEST IS PASSED.

INPUT VALUE OF PROBABILITY OF PASSING TEST WITH ETA OF FAIL MODE.
THIS ONE MINUS THE PERCENT CONFIDENCE OF THE VALUE OF ETA USUALLY
0.1

A0=?.1

INPUT VALUE OF PROBABILITY OF PASSING TEST WITH ETA DESIRED
THIS IS THE PERCENT CONFIDENCE OF ETA DESIRED - USUALLY 0.9

A1=? .9

INPUT VALUE OF ETA FOR FAIL MODE? 15788

INPUT VALUE OF ETA DESIRED? 22000

INPUT NUMBER OF TEST HOURS FOR EACH TEST ARTICLE? 10000

INPUT VALUE OF BETA FOR FAIL MODE? 4.051
```

FIGURE 56: NZFTESTP SCREEN 1

```
A0= .1  A1= .9       ETA0 = 15788  ETA1 = 22000   TEST HOURS = 10000
BETA = 4.051

A0  G0        N0    A1     G1        N1      M          R0
.1  .1106448  14    .9     .8842481   3   16.90104      0
.1  .1031518  25    .9     .9061068  13   6.964714      1
.1  .1098778  34    .9     .9072676  27   4.560598      2
.1  .1104666  43    .9     .9066738  43   3.621651      3
0   0         0     0      0         0    0             4
0   0         0     0      0         0    0             5


NOW SELECT THE LAST TWO VALUES OF M AND COMPARE THEM WITH :

              N = 3.621651


THE FINAL VALUE OF N0 AND N1 ARE THE VALUES WHICH ARE IN THE ROW
VARIABLES THAT CONTAINS THE VALUE OF M CLOSEST TO THAT OF N -
EITHER + OR -.:?

INPUT THESE VALUES OF N0 AND N1 AT THE PROMPTS

INPUT N0:
?   43
INPUT N1:

?   43
INPUT R0:

?   3
```

FIGURE 57: NZFTESTP OUTPUT SCREEN 1

```
THE SAMPLE SIZE, EACH OF WHICH MUST BE TESTED FOR 10000 HRS, IS:
              SAMPLE SIZE = 43

IF 3 OR LESS FAILURES OCCUR THE TEST IS PASSED,

MAXIMUM TOTAL TEST HOURS IF ALL TEST UNITS RUN W/O
FAILURE = 430000
```

FIGURE 58: NZFTESTP OUTPUT SCREEN 2

NOTES: Since the sample size is rather large, a longer test time is probably in order. Again, the process can be iterative to optimize between numbers of test articles and test hours.

PROGRAM 15. GRAPHICS DISPLAY FOR WEIBULL PLOT

This code is used in conjunction with routine one. For a given sample of data this code calculates the Weibull parameters BETA and ETA and plots the data on Weibull coordinates. Files created by routine one can be retrieved here and used to make the plots.

Input data:

1) Same as for routine one.

Output data:

1) Calculated values of BETA and ETA.
2) Weibull graph or plot.

The Weibull Plot routine will generate four different types of plot. These are:

3 cycle rank regression
5 cycle rank regression
3 cycle maximum likelihood
5 cycle maximum likelihood

Examples of these can be seen in figure 60 through 63, respectively.

Note that the user can obtain a hard copy of the Weibull plot by performing a print screen (press Shift-Print together). If a problem arises, it may be required to load the computer routine Graphics.Com onto the floppy disk that is unique to the computer being used. It is also sometimes necessary to load the routine Command.Com as well.

GRAPHICS DISPLAY FOR WEIBULL PLOT
YOU MUST NOW GO TO DOS AND ENTER <WEIBL> TO VIEW YOUR WEIBULL PLOT
PRESS ENTER TO GO TO DOS

FIGURE 59: GRAPHICS DISPLAY SCREEN 1

NOTES: Upon selecting routine 15 from the main menu, screen 1 will appear. At this time press enter to exit to DOS and load the graphics by entering WEIBL. Use this code as you use code number 1. Note there is a help file activated by pressing <alt-h>. Pressing <end> terminates the graph from the screen which may be recalled if done in error. Instructions are self explanatory.

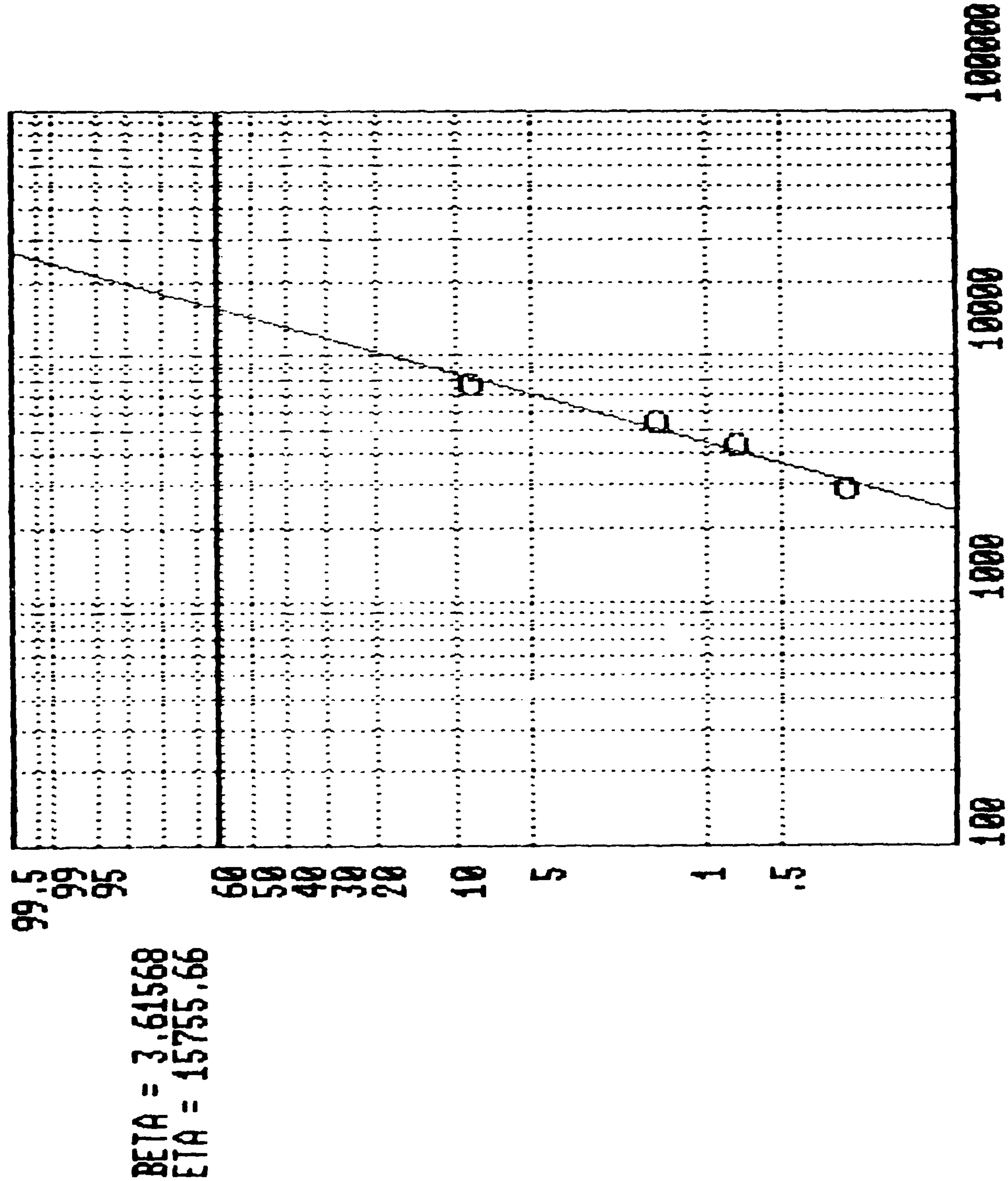

Figure 60 THREE CYCLE RANK REGRESSION PLOT

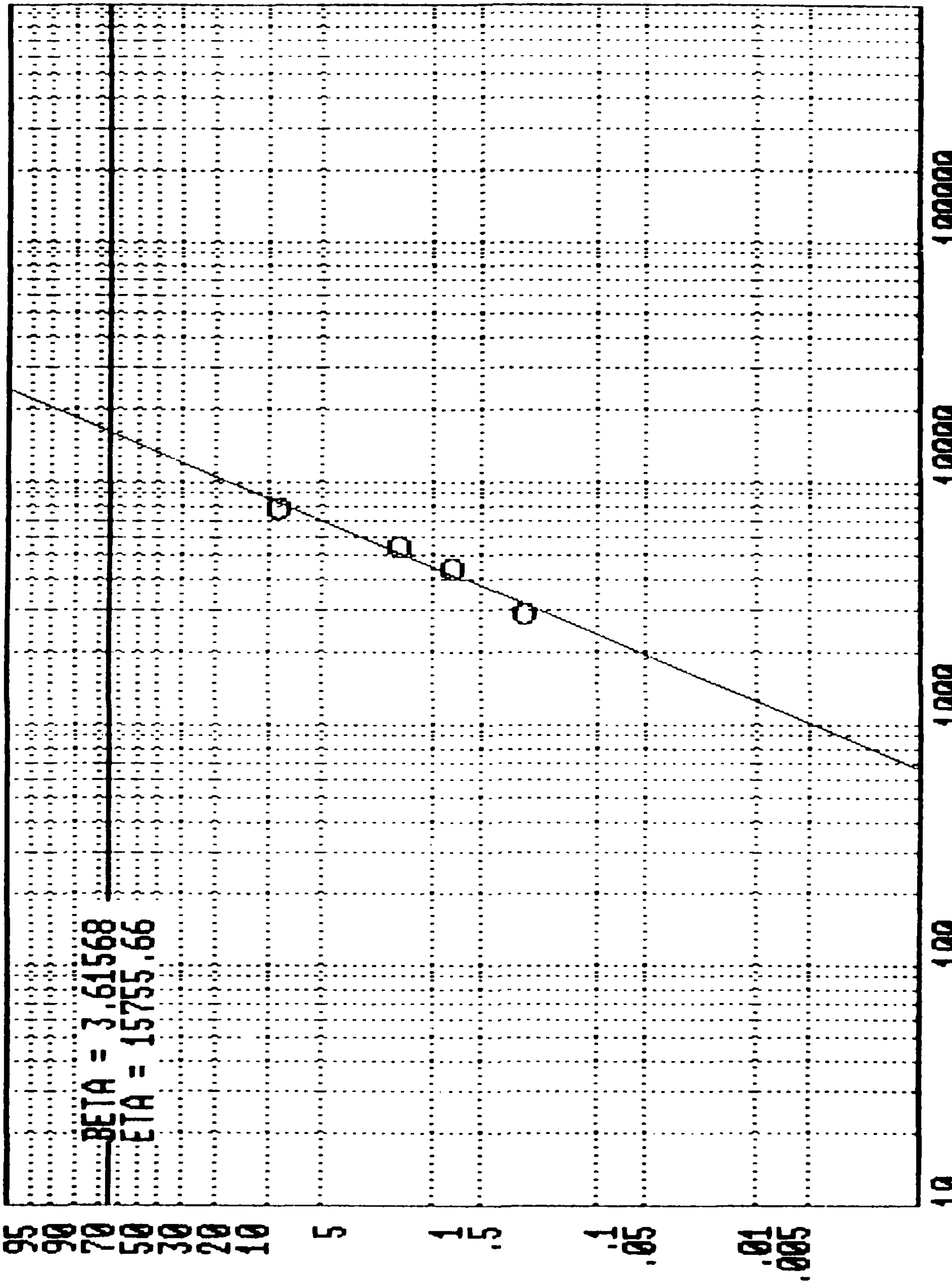

Figure 61 FIVE CYCLE RANK REGRESSION PLOT

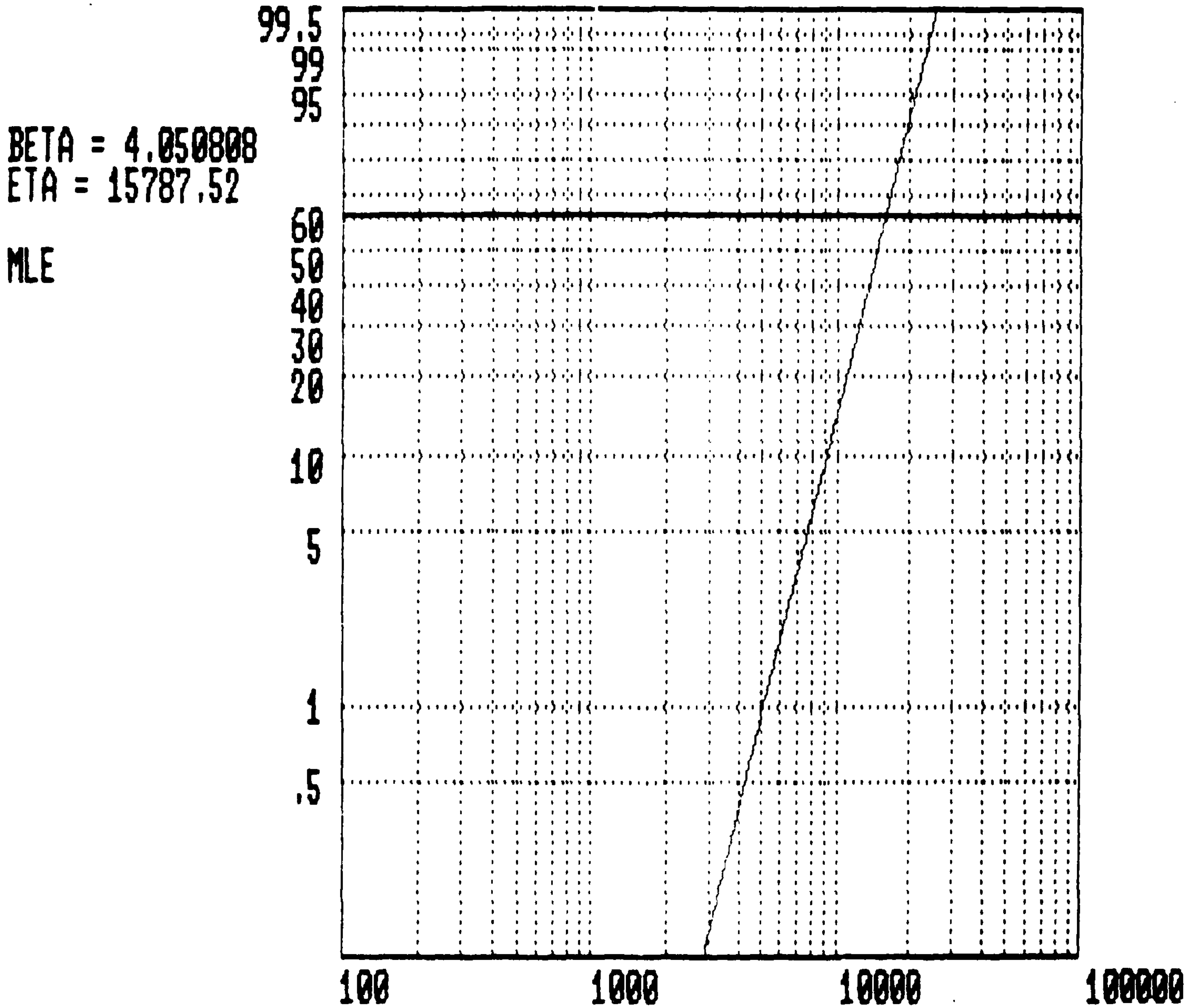

Figure 62   THREE CYCLE MAXIMUM LIKELIHOOD PLOT

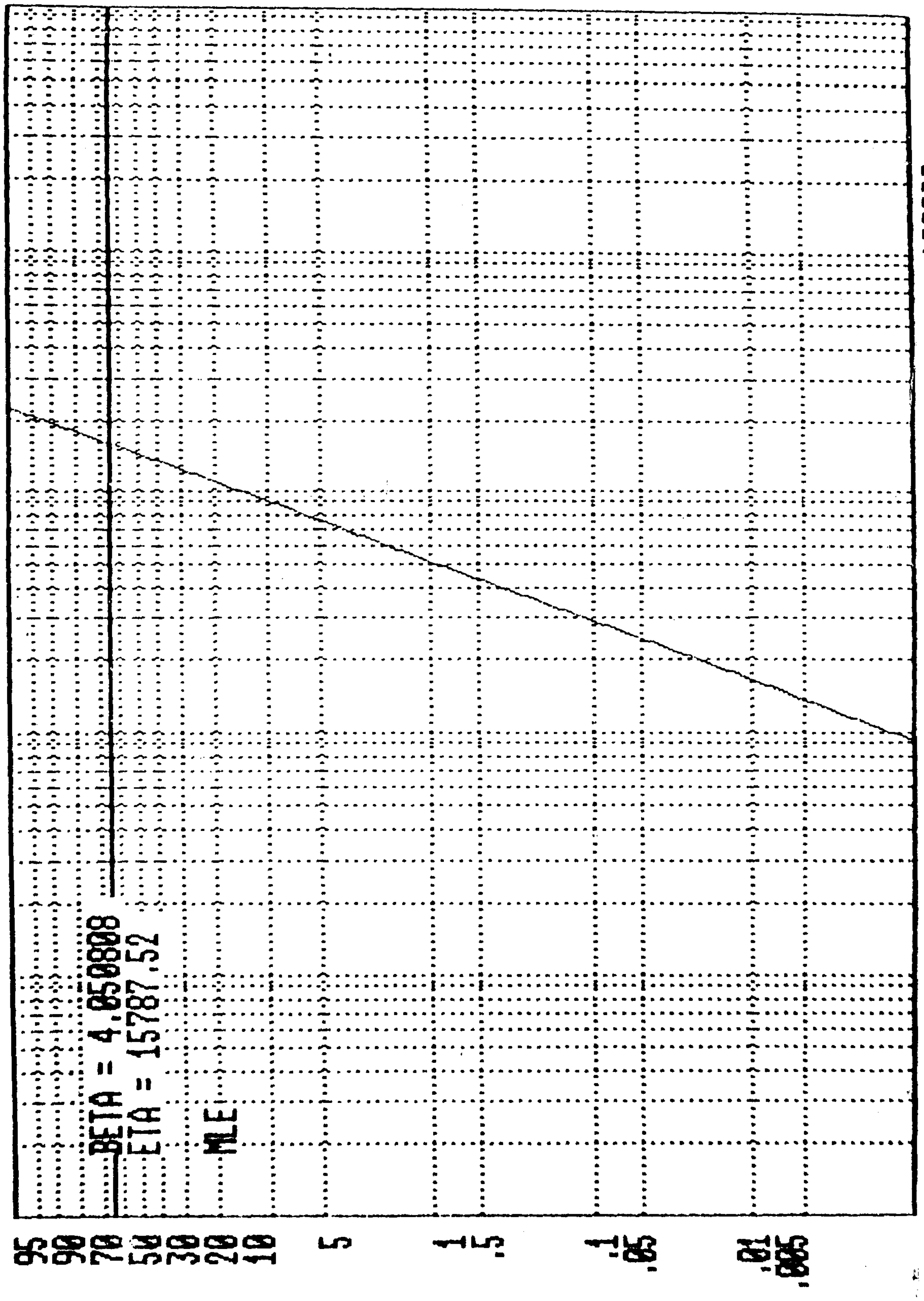

Figure 63 FIVE CYCLE MAXIMUM LIKELIHOOD PLOT

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